Structure and Measurement of the brain lecture notes

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2009/2010

Based on slides from Flavia Filimon, 2008

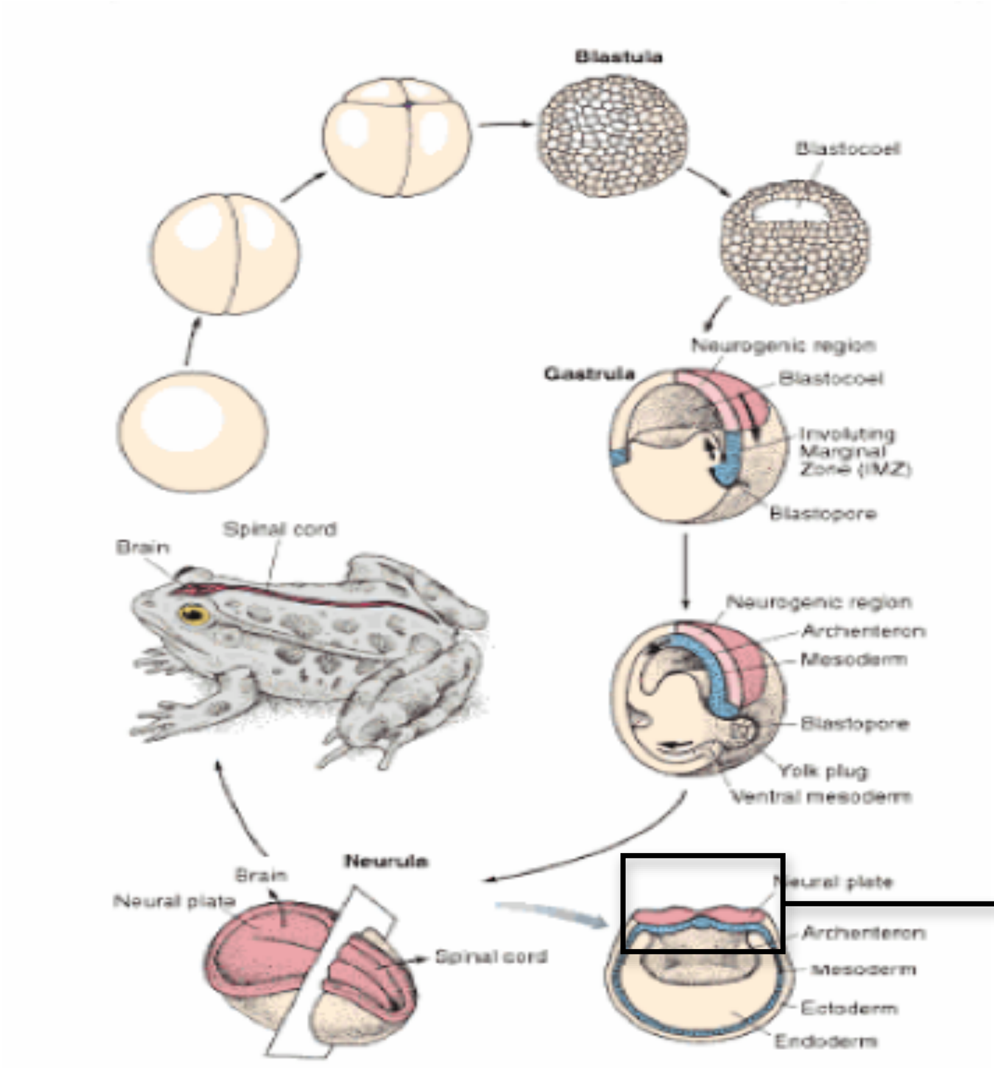
Neural development and visual system

Lecture 2

Topics Development

- Gastrulation
- Neural plate/Neural tube
- Cylindrical coordinate system of the neural tube
- Optic cup
- The Rule of Sereno

Gastrulation

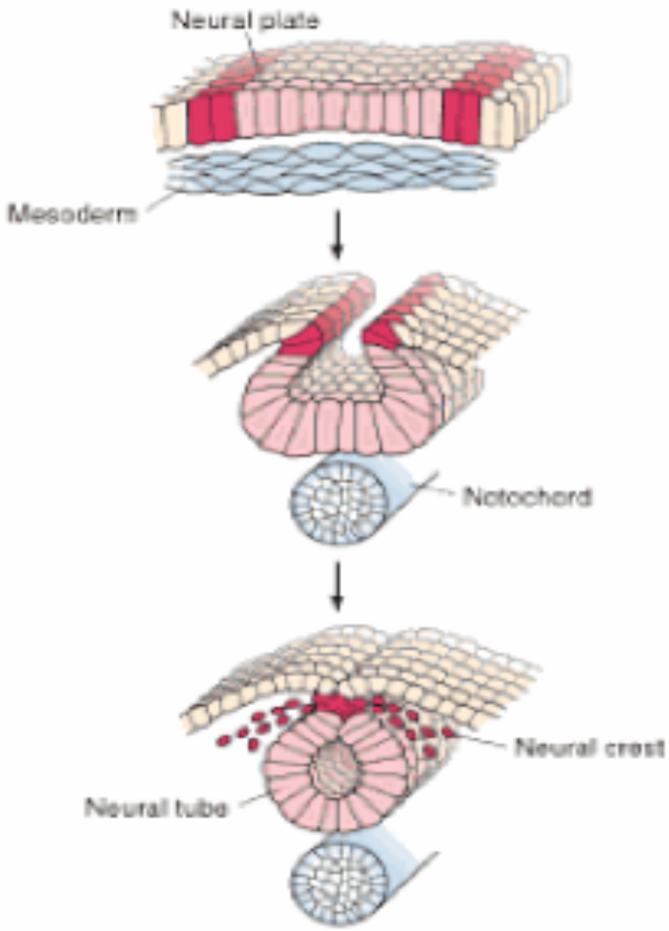


Blastula to Gastrula:

Cells contract down into intestine tube.

Where tube closes at top, the neural neural plate is formed

Neural Plate

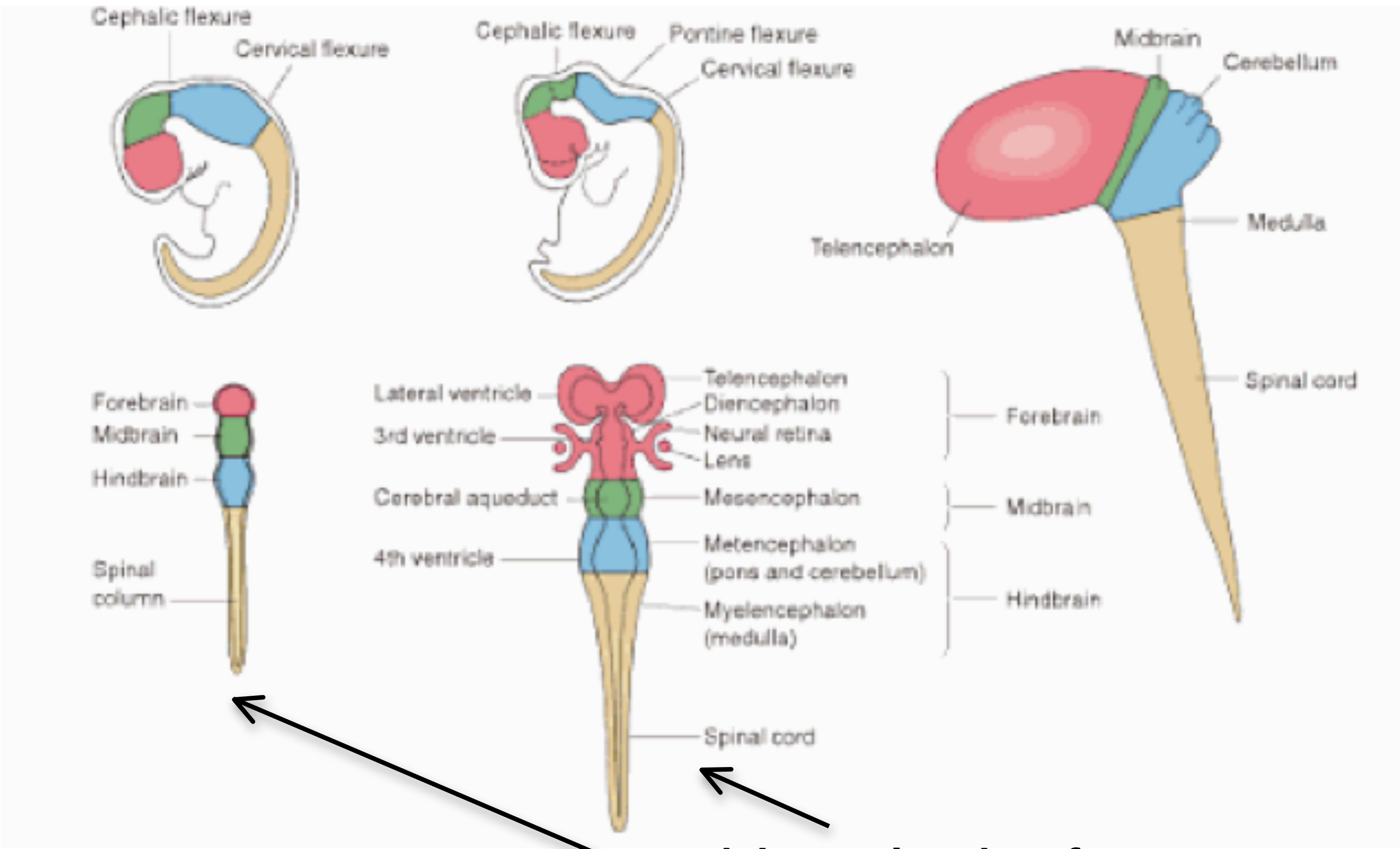


Neural plate to tube:

Neural plate cells contract down to form the neural tube

If we look at the neural tube from the top…

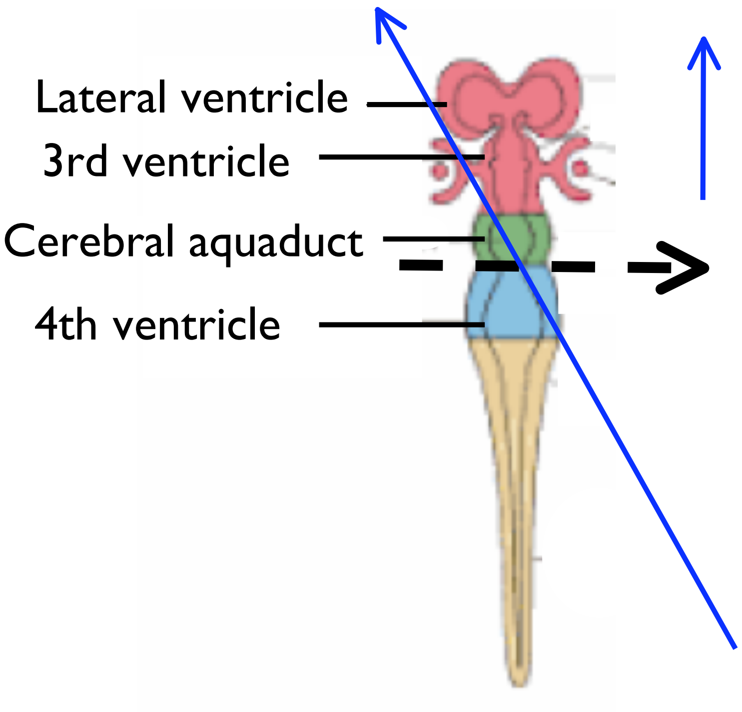
Cylindrical coordinate system neural tube to nervous system



Neural tube from top

Rule of Sereno

EVERYTHING GETS FLIPPED AT PONS/MIDBRAIN JUNCTION



The connection between two structures on

SAME side of junction stays on same side of brain

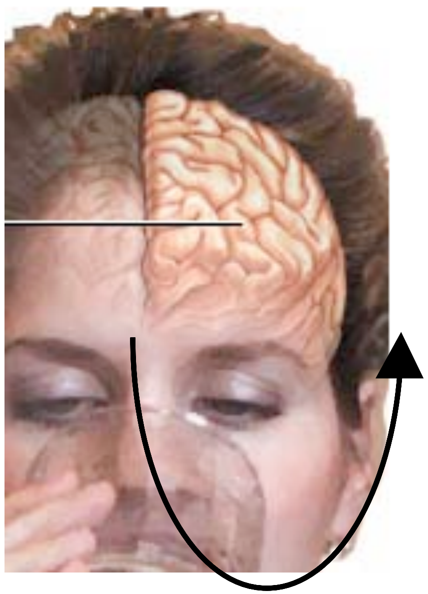
OPPOSITE sides of junction crosses to other hemisphere

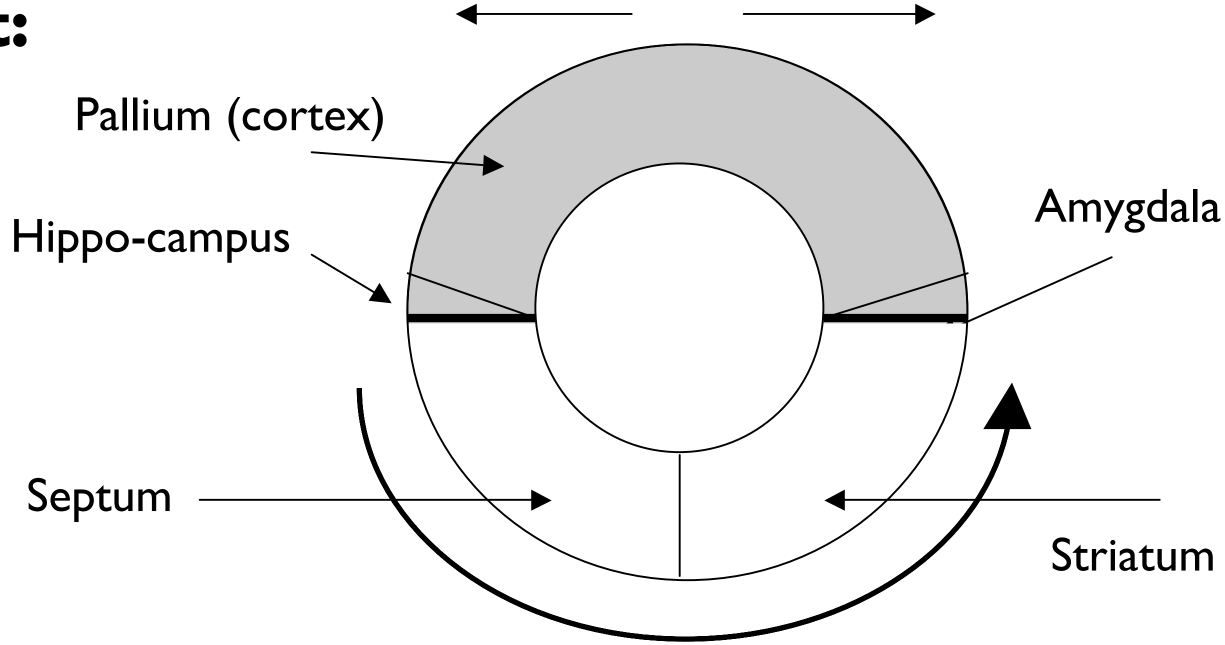
Temporal lobe formation

- Hippocampus migrates from dorsal/medial pallium to amygdala *underneath* temporal lobe

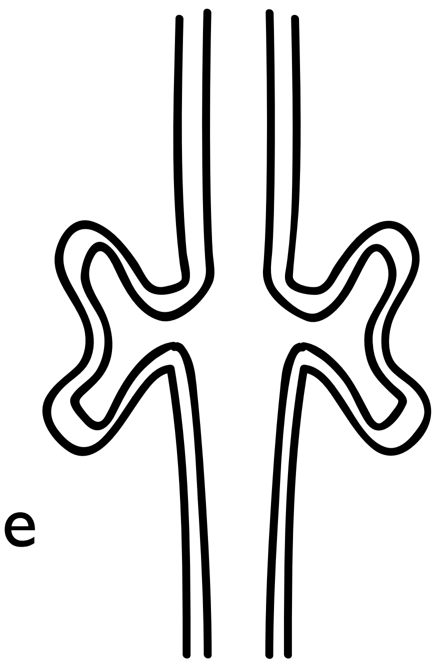
<u>Left</u> forebrain

seen from front:



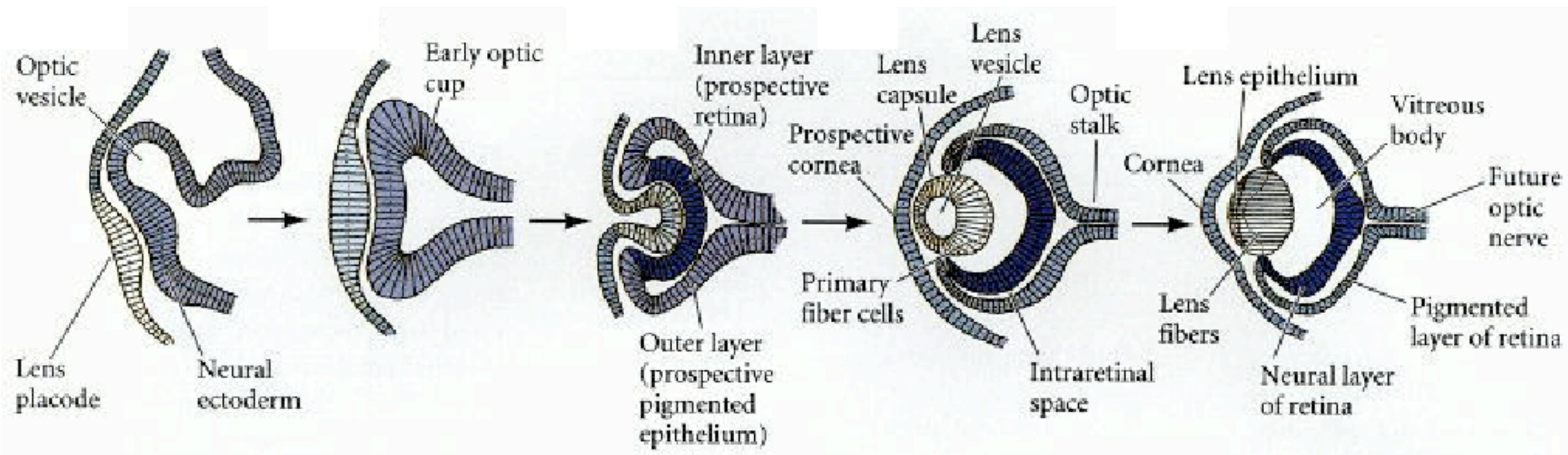


Retina



- retina develops as an out-bulging of the brain in the embryo, → part of the CNS
- retina is in-side out - the light-absorbing part of the photoreceptor is closest to the brain and farthest from the light source
- squid, invertebrates: retina is right-side out (photoreceptors exposed to light)
- low acuity (but: dark pigment epithelium in humans)

Optic cup formation



Topics Visual system

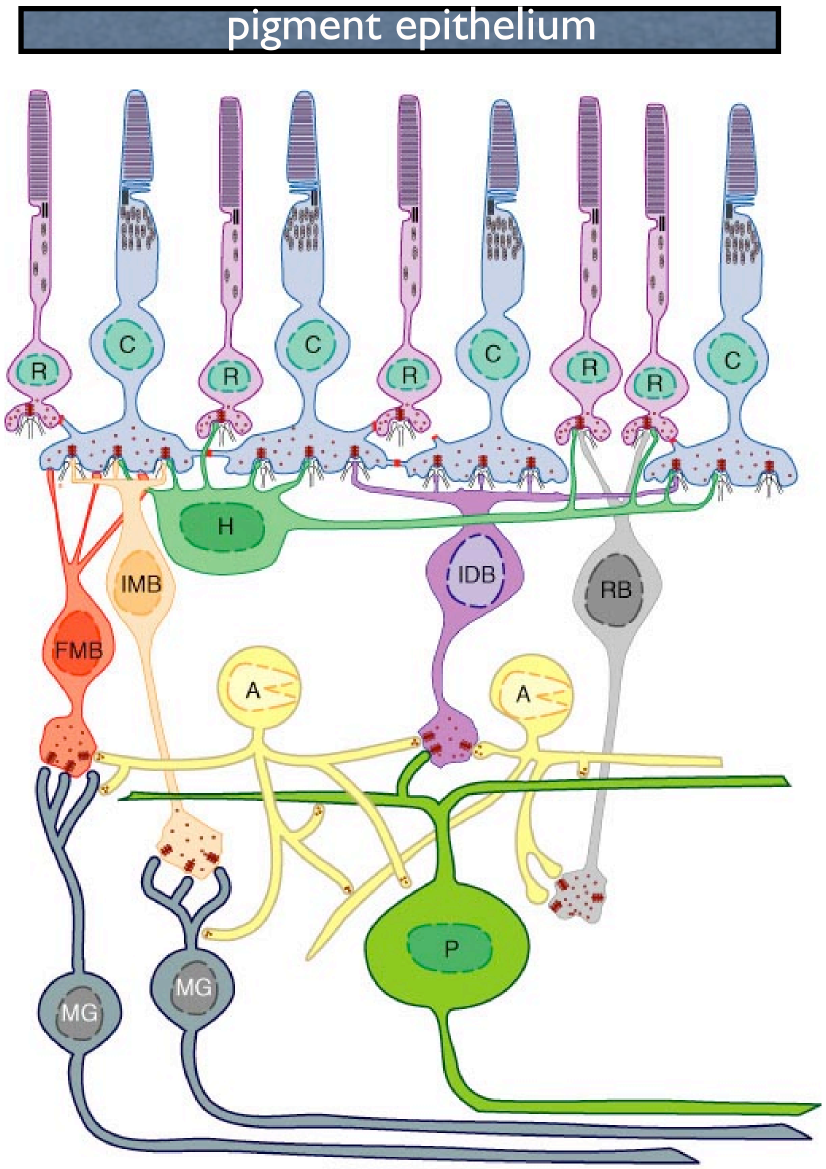
- Retinal circuitry
- Edges and primary motion in V1
- Visual map structure (conformal maps)
- Cortical visual processing streams
- Visual pattern motion: the aperture problem

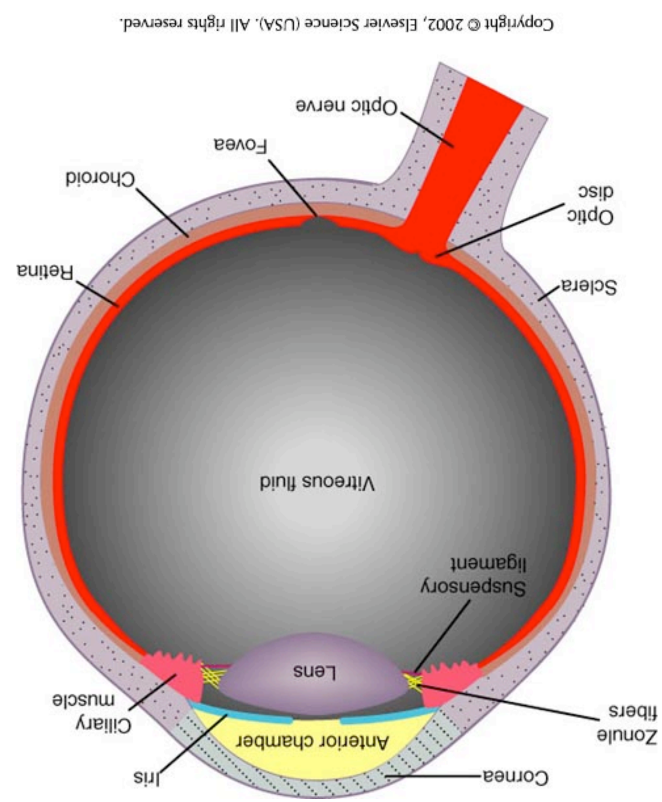
Retina

1

2

3

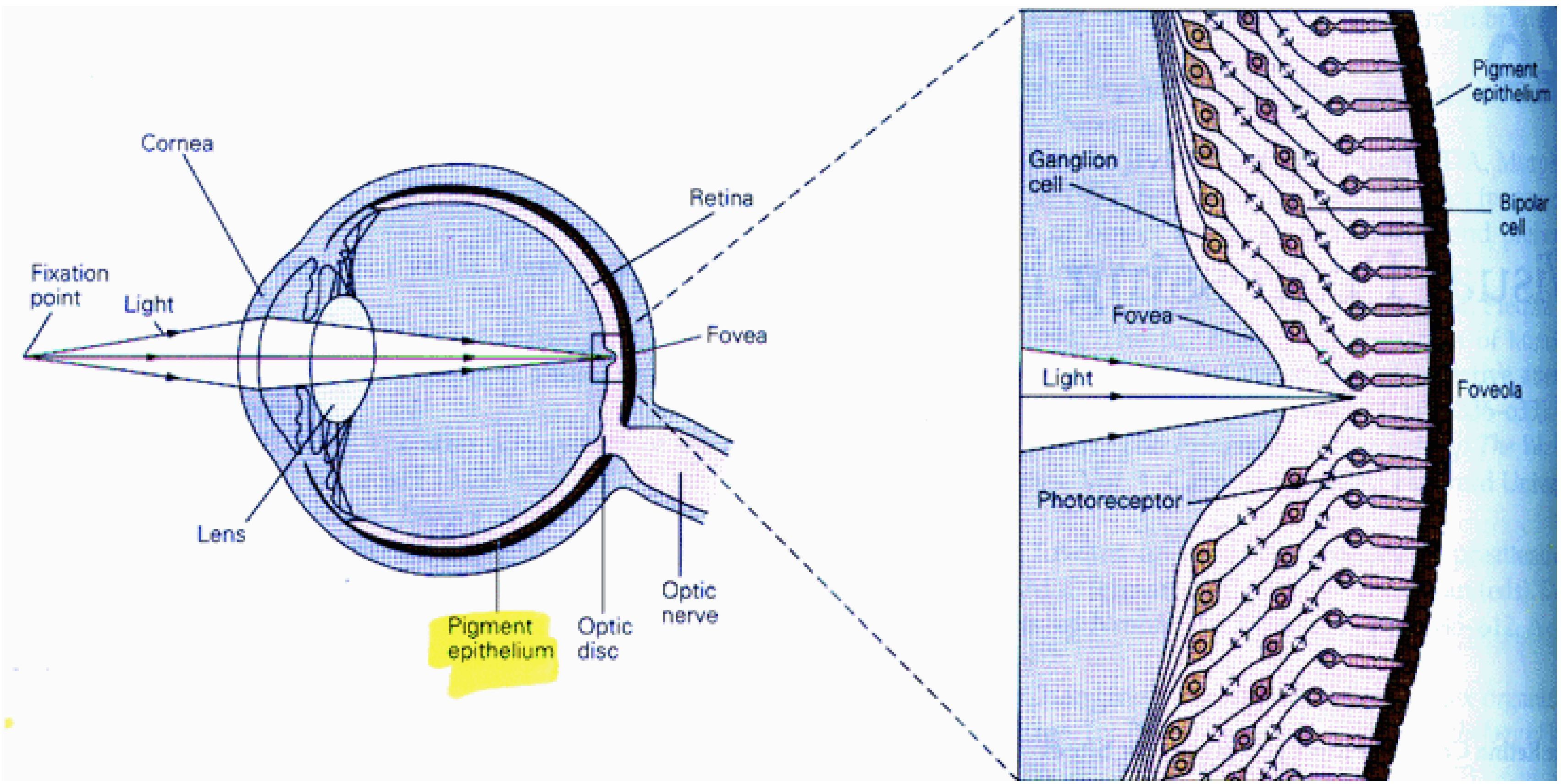




light

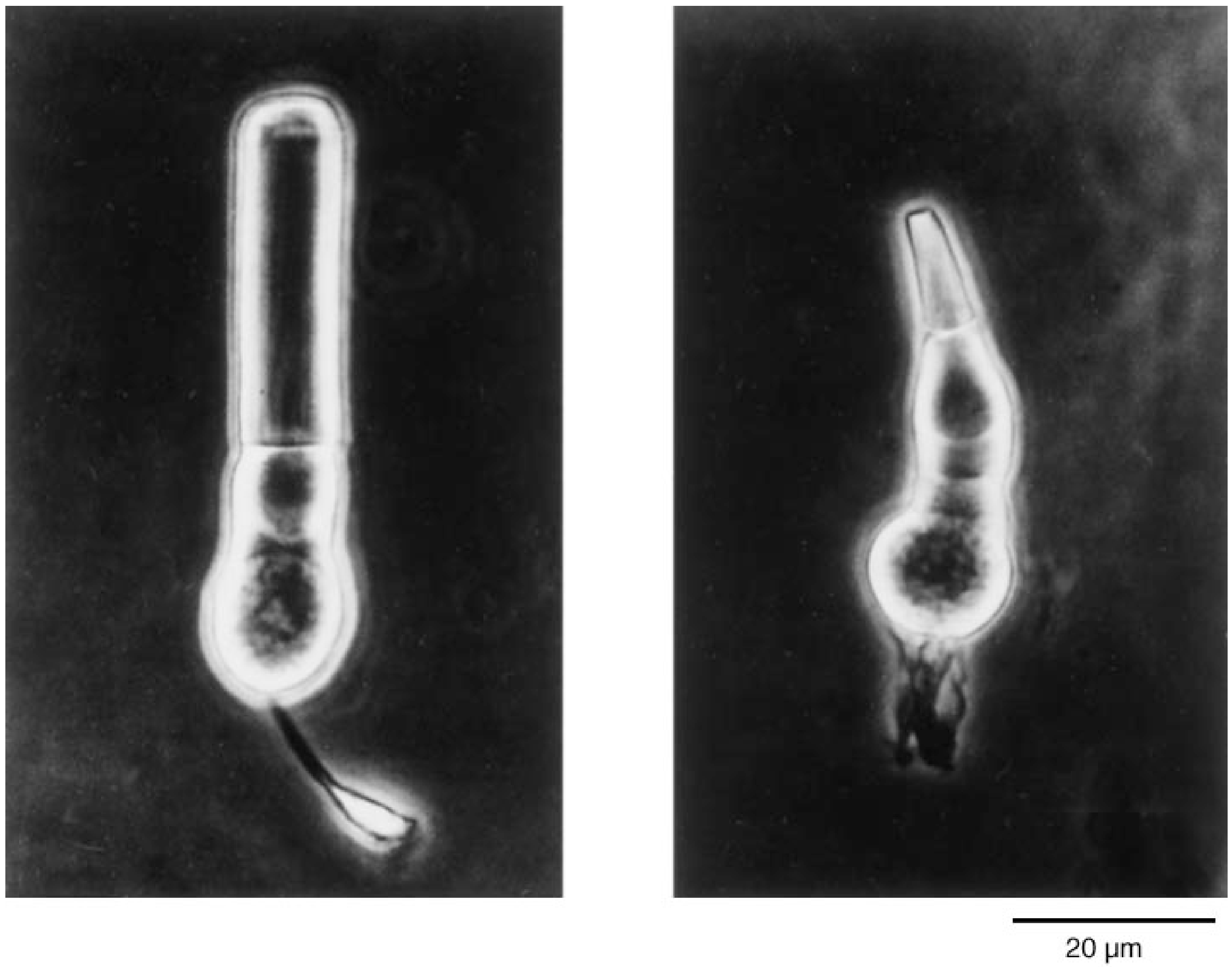
1: photoreceptor layer; 2: interneuron layer; 3: ganglion cell layer

Fovea: light accesses photoreceptors directly



from Kandel, Schwartz, and Jessell, 2000

Two types of photoreceptors



Two types of photoreceptors

- **rods**: visual pigment rhodopsin:

  - night vision; high sensitivity; low-acuity

- **cones**: visual pigment photopsin:

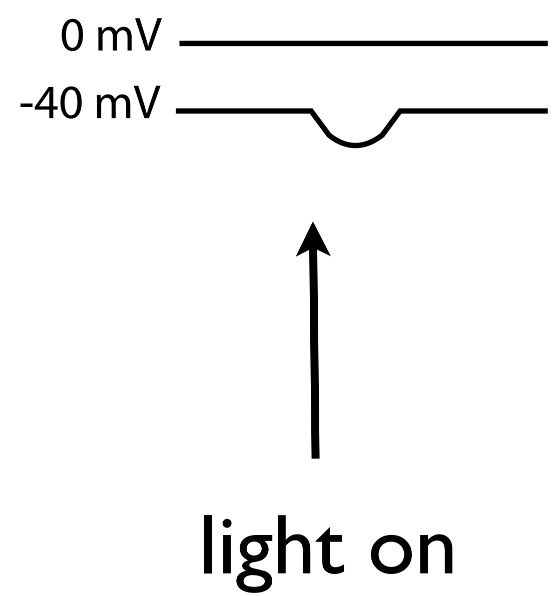
  - color vision; low sensitivity; high-acuity

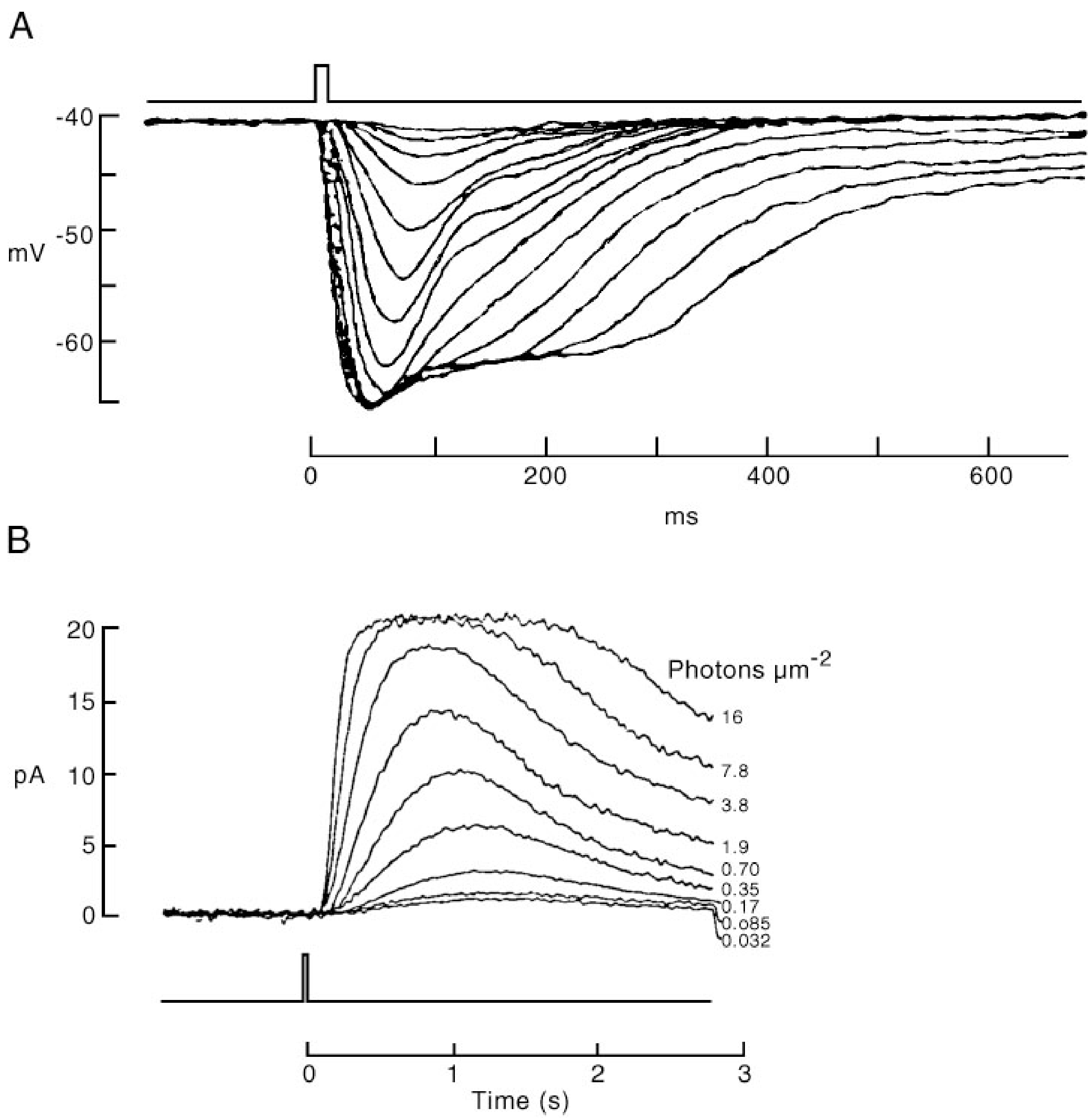
  - short (S), middle (M), and long (L) wavelength absorption (blue, yellow/green, red)

- normal human vision is trichromatic

Photoreceptors are hyperpolarized by light

- rods and cones do not spike (no action potentials) - they respond with graded hyperpolarizations (due mainly to suppression of inward Na + ions)
- photoreceptors are normally in a depolarized state (resting state)



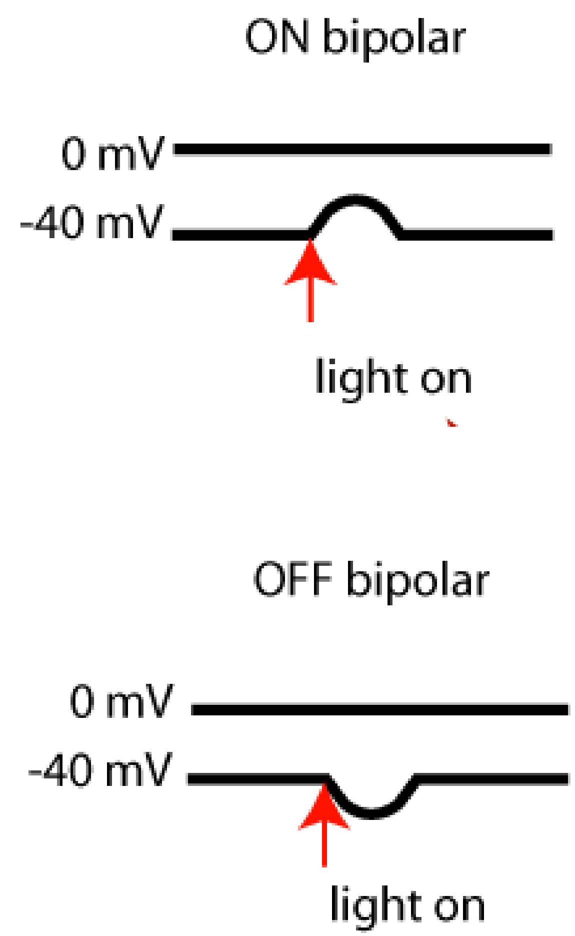


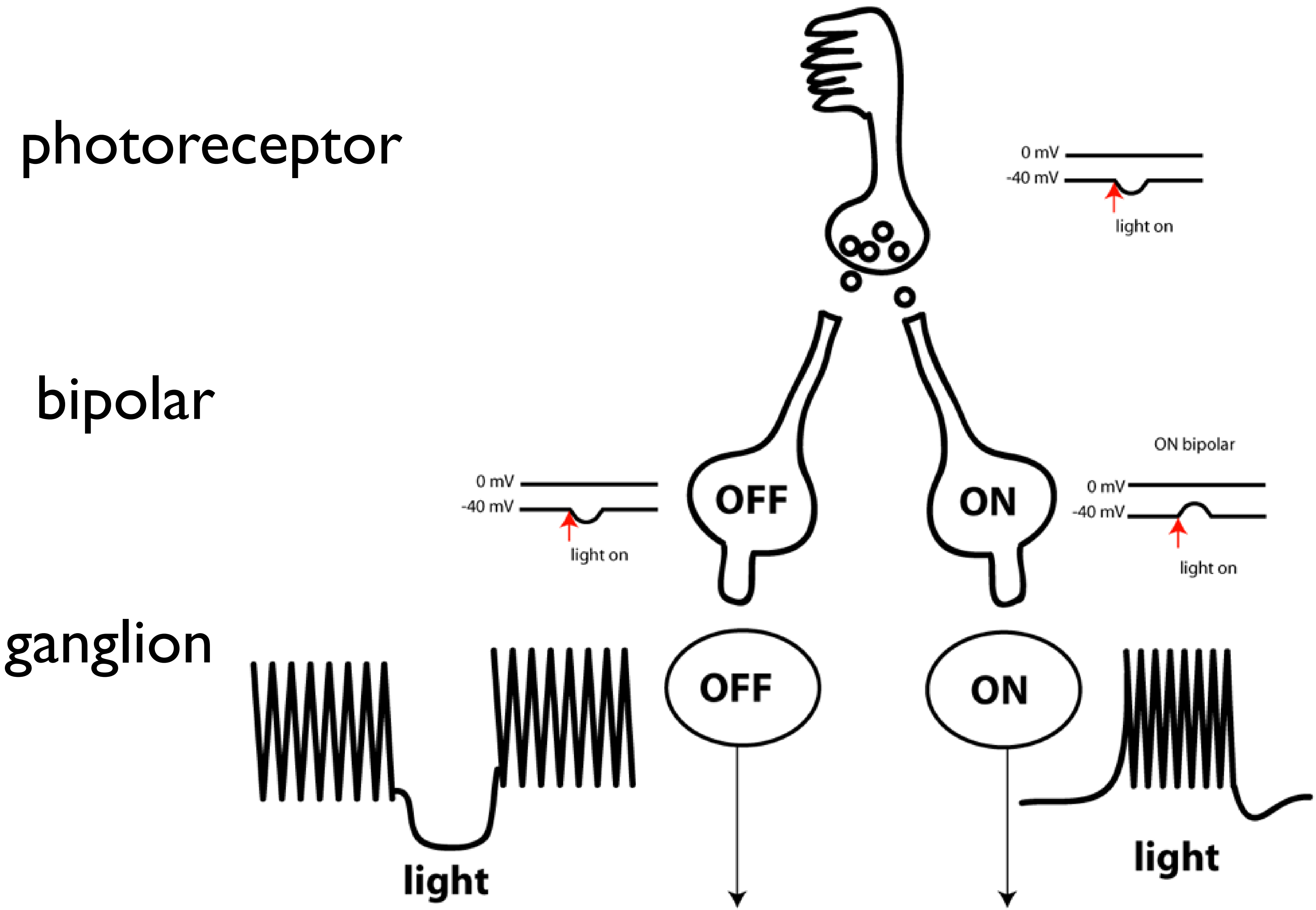
cone response to light in turtle retina

- graded hyperpolarizations in photoreceptors depend on amount of light

Bipolar cells are either hyperpolarized (OFF) or depolarized (ON)

- ON bipolars: result from removal of inhibition, when photoreceptors are hyperpolarized by light
- OFF bipolars: removal of tonic excitation, when photorecept. are hyperpol. by light
- photoreceptors release glutamate in absence of light
- Glu is inhibitory for ON bipolars

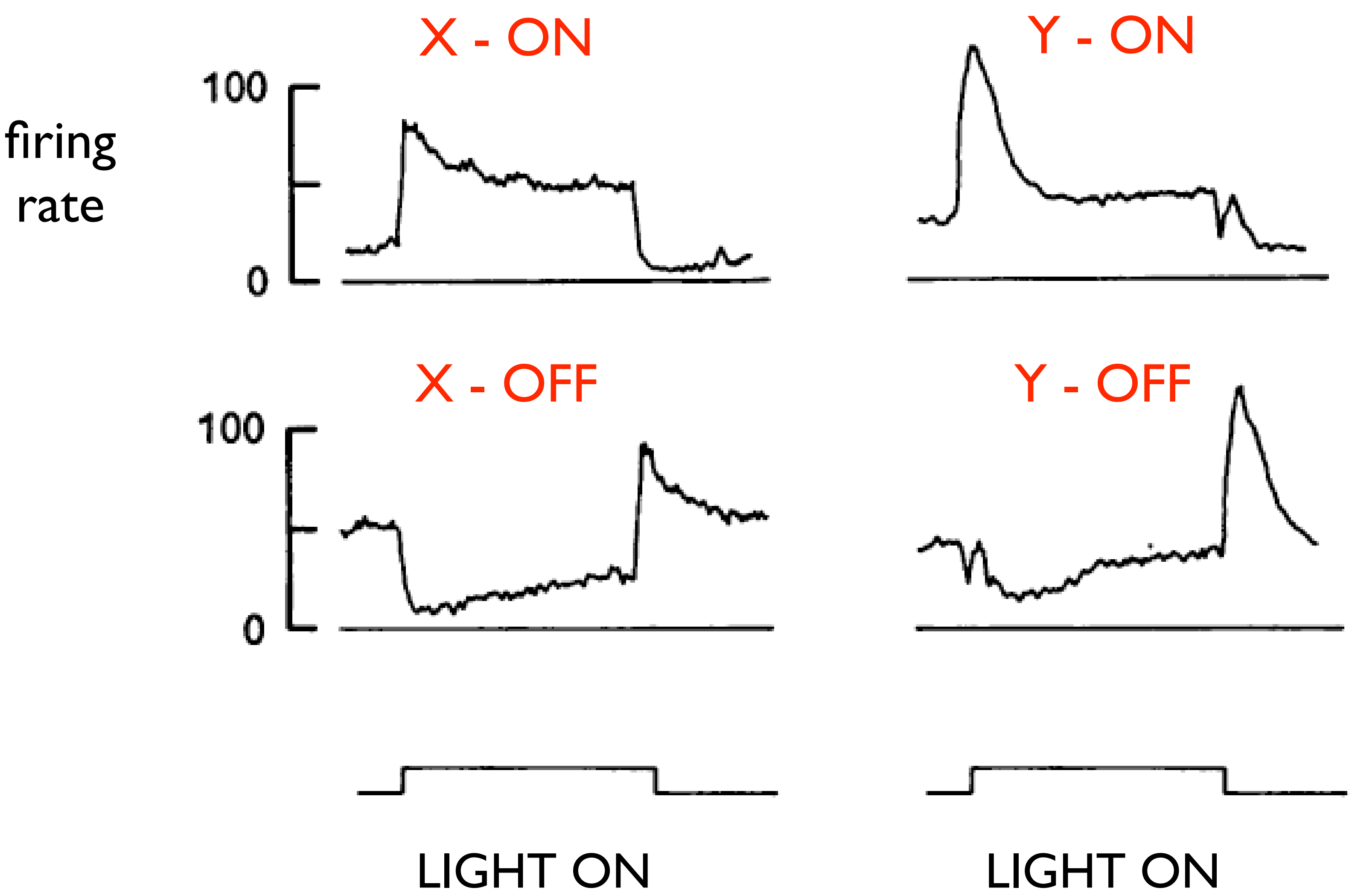



photoreceptor
bipolar
ganglion
0 mV
-40 mV
light on
ON bipolar
0 mV
-40 mV
light on
0 mV
-40 mV
light on
OFF
ON
OFF
ON
light
light

Retinal ganglion cells

- ganglion cells are the output cells of the retina and the only ones that spike
- parasol = M = Y (transient, large cells): magno
- midget = P = X (sustained, small cells): parvo
- P cells are sensitive to color, M cells are not - instead, sensitive to contrast

X-ON, X-OFF, Y-ON, Y-OFF ganglion cells

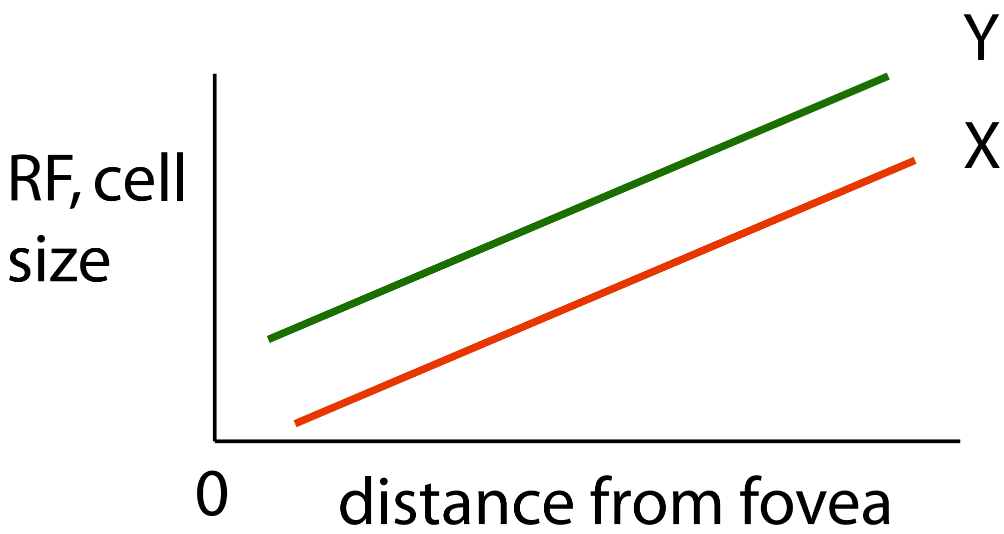


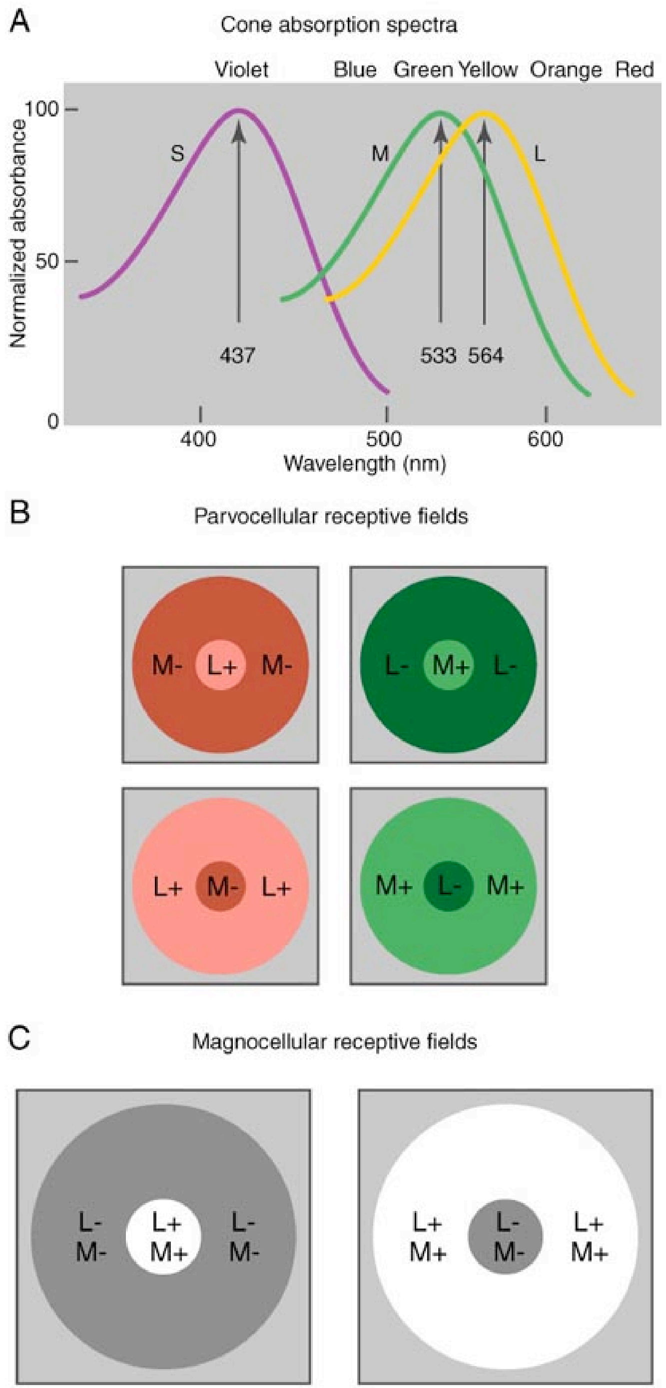
Enroth-Cugell and Robson, 1966

- X-cells re-produce the stimulus; Y-cells tell you the DERIVATIVE of the stimulus
- note: both sustained (X) and transient (Y) cells have elements of transientness and sustainedness, respectively

X and Y transientness in retina

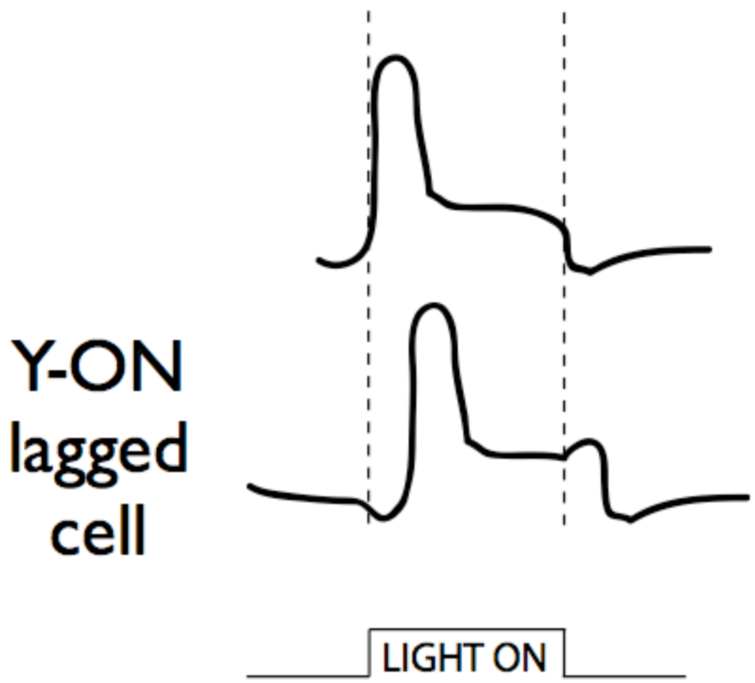
- the more peripheral a cell, the greater its cell size and its receptive field
- also, the more transient

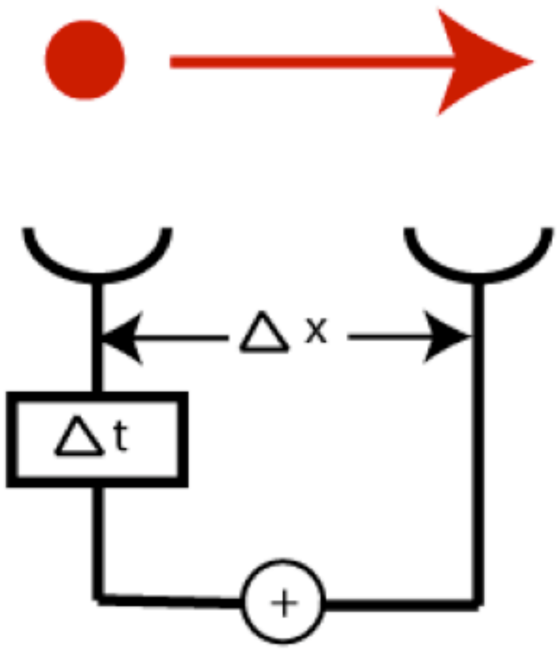




- Red-green & blue-yellow color opponent P/parvo cells in retina/LGN
- e.g. receiving L cone input in center and M cone input in surround
- M cells receive mixed input from L and M cones

Motion Detection Model

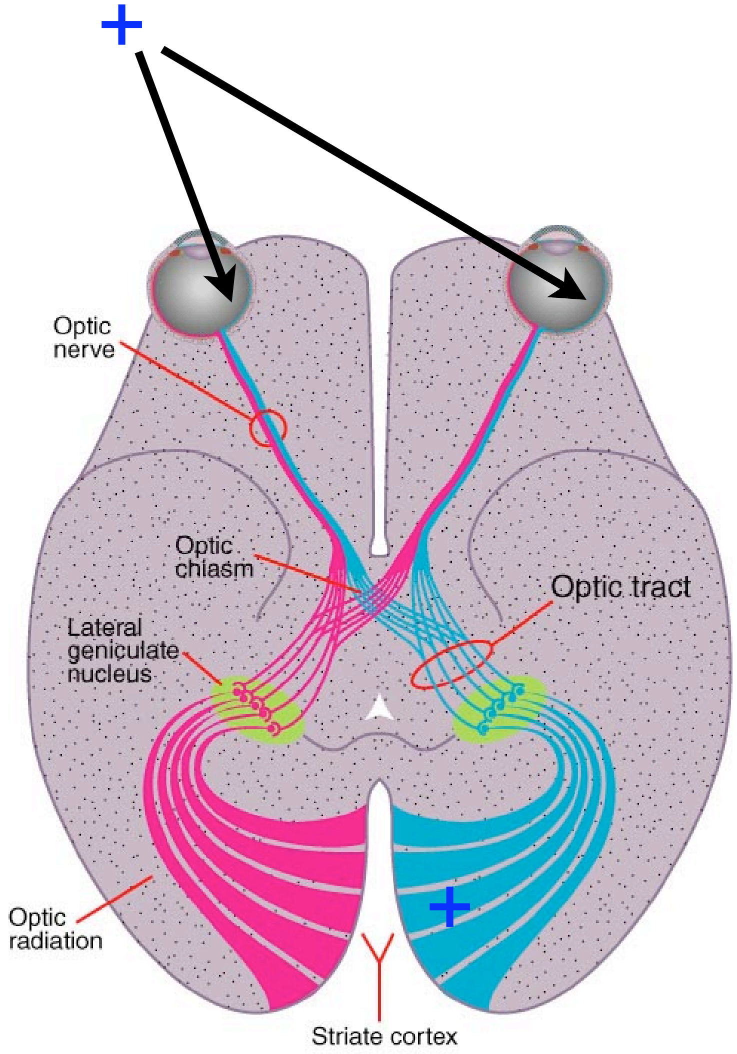


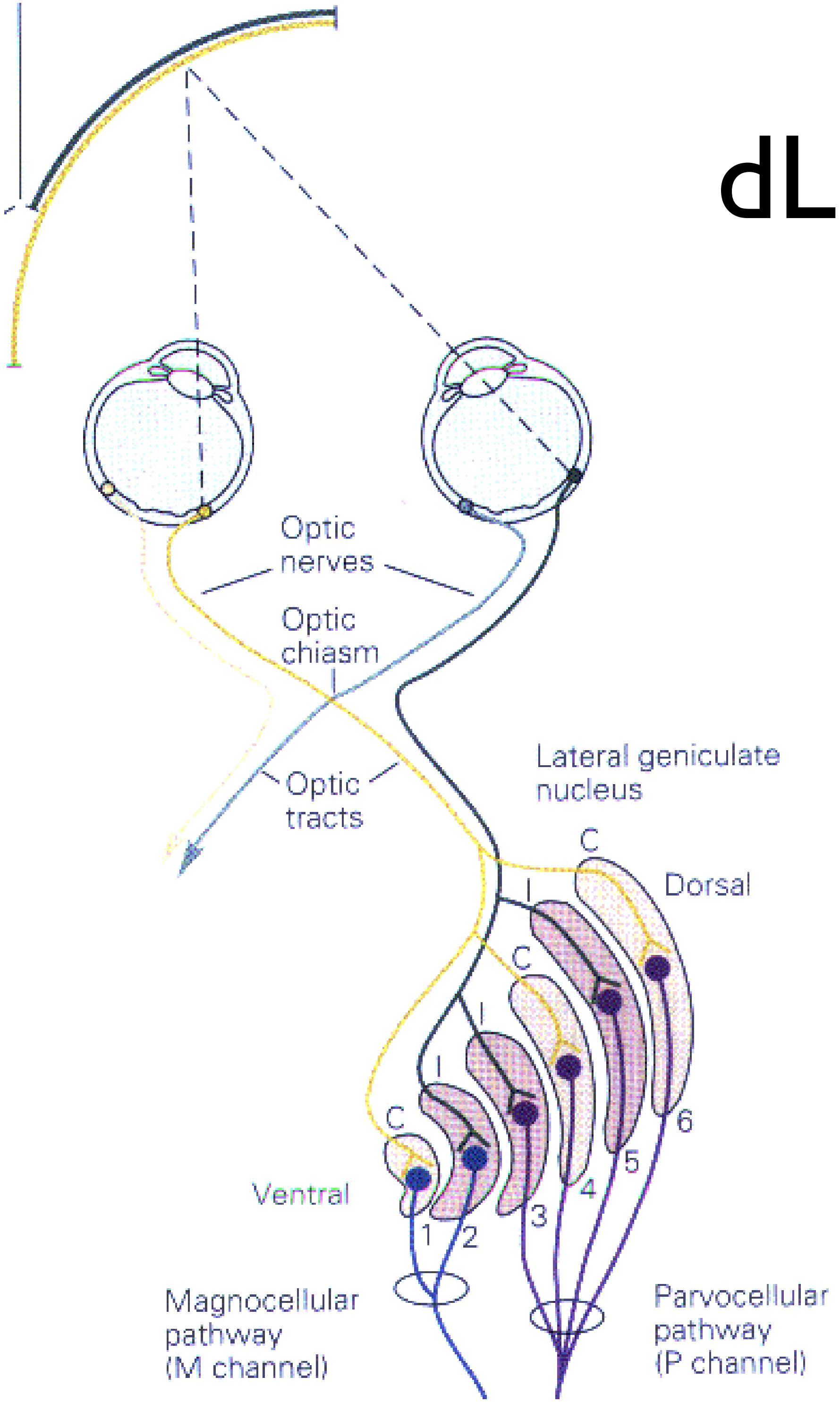


- Lagged x and y cells in cat dLGN (lagged x-on, lagged x-off etc)
- This function seems to be moved up to V1 -not dLGN in primates
- Reichard detector

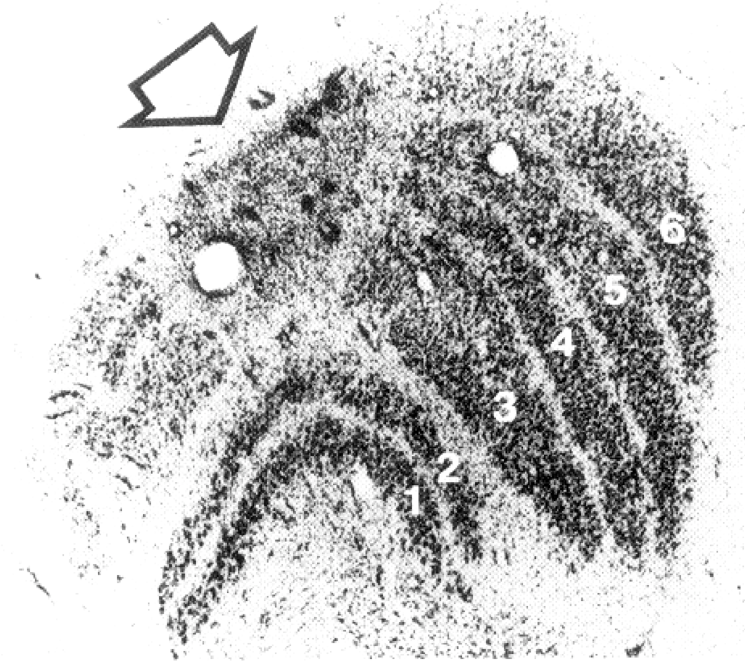
From retina to dLGN

- inverted image due to optics of the eye
- temporal hemiretinas: **ipsi**
- nasal hemiretinas: **contra**





dLGN



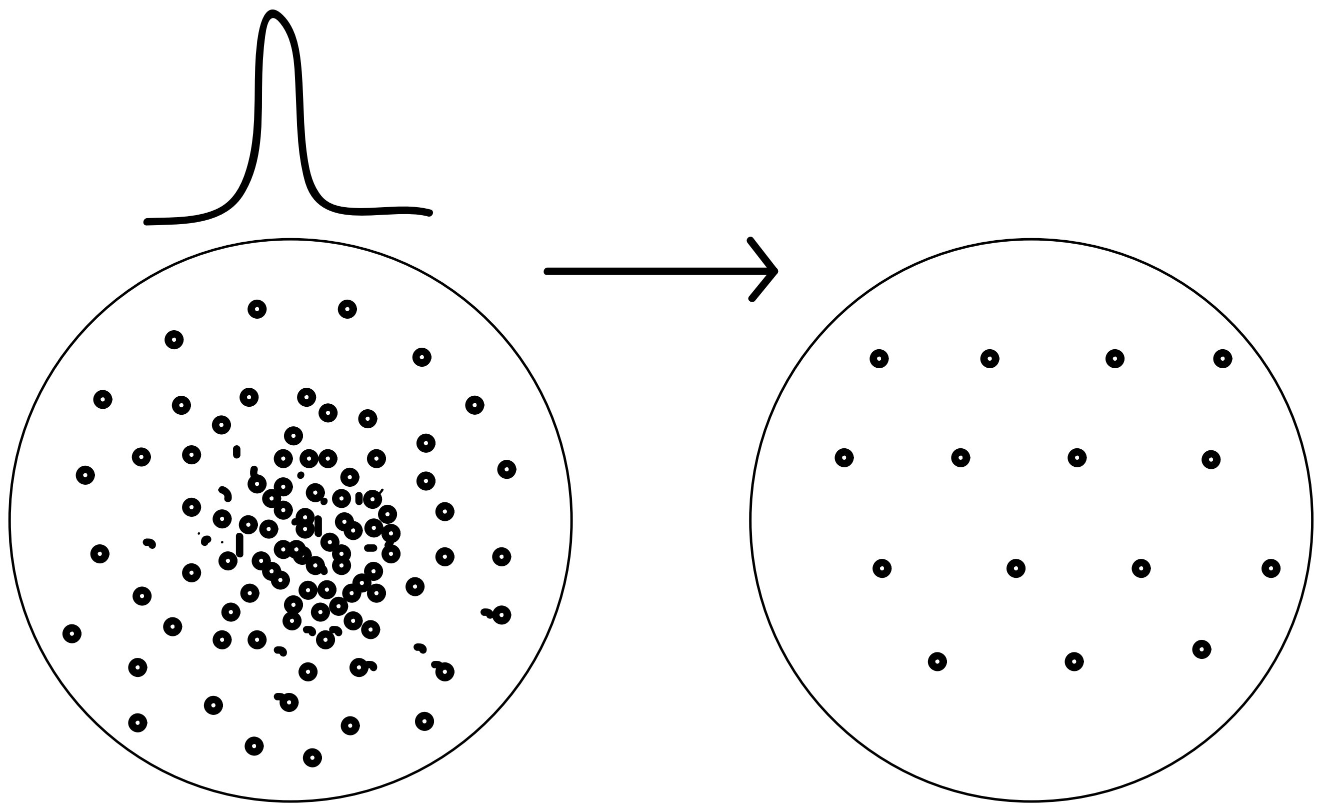
- 6 LGN layers; ipsi and contra-lateral projections from retina to LGN layers
- parvocellular, magnocellular, koniocellular

from Kandel, Schwartz, and Jessell, 2000

Why the pattern of projections from the nasal and temporal hemiretinas?

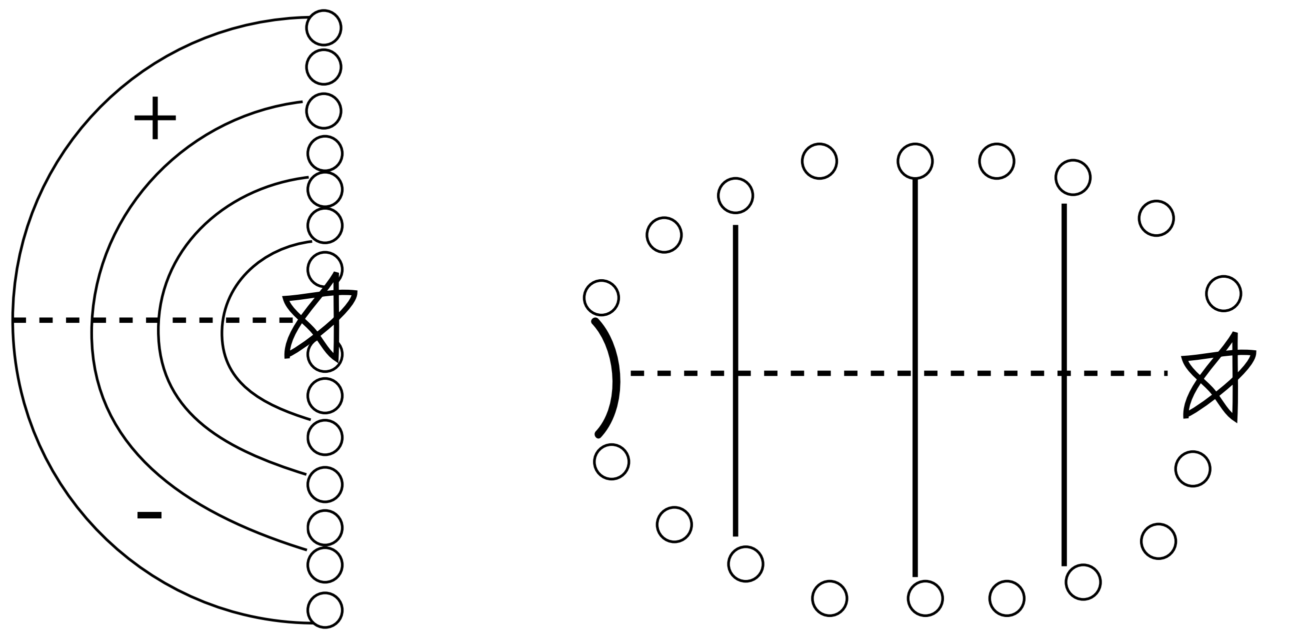
- forward-facing eyes: the eyes overlap
- hence information from one part of the visual field should be combined (regardless of which eye it came from)
- → **left** *visual field* to **right** brain; etc.
- aligned retinotopic maps of one visual field in each LGN
- optic chiasm

Photoreceptor density is greatest in fovea



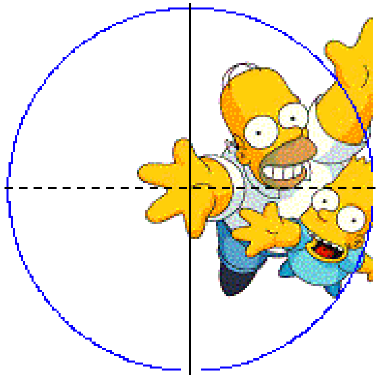
- Therefore, how can we spread out axons without distorting the objects represented?

LGN is an approximately conformal map

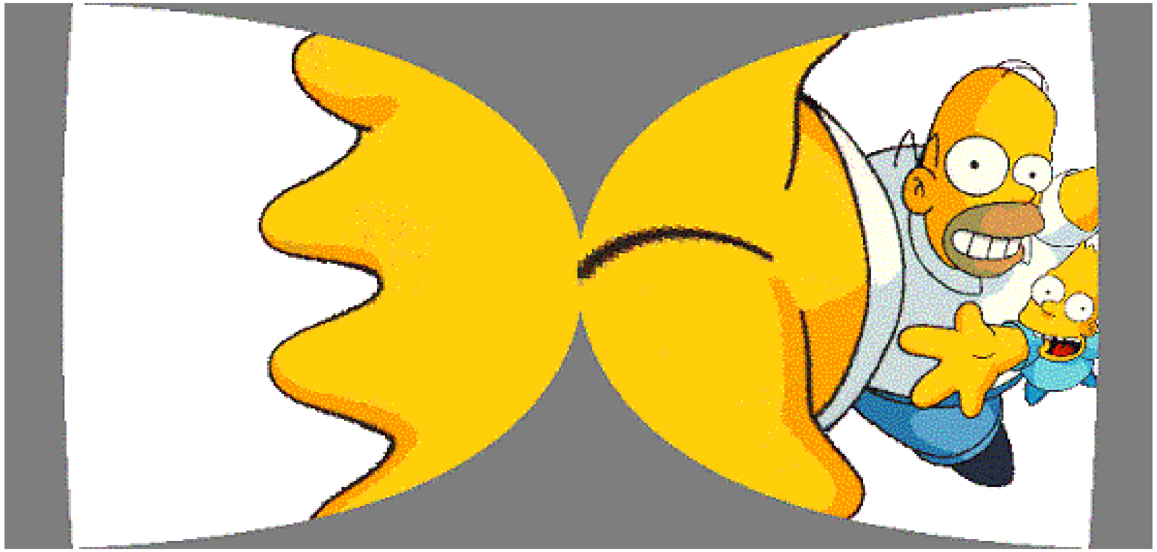


Conformal map: preserves local angles, shape; but not size
But: you still have an enlargement at center of gaze

Foveal enlargement in LGN/V1

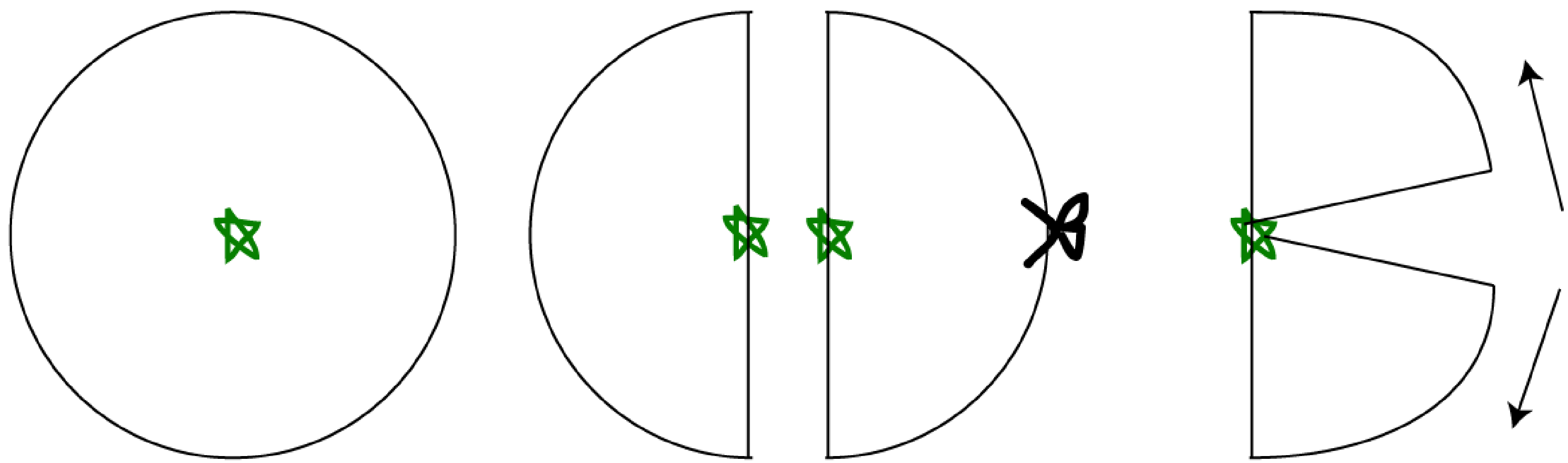


- http://cns.bu.edu/~arash/tracking_research.htm



(does not show left-right reversal or contralaterality; also periphery should be lower-res.)

Further subdivisions of the visual map occur beyond the LGN

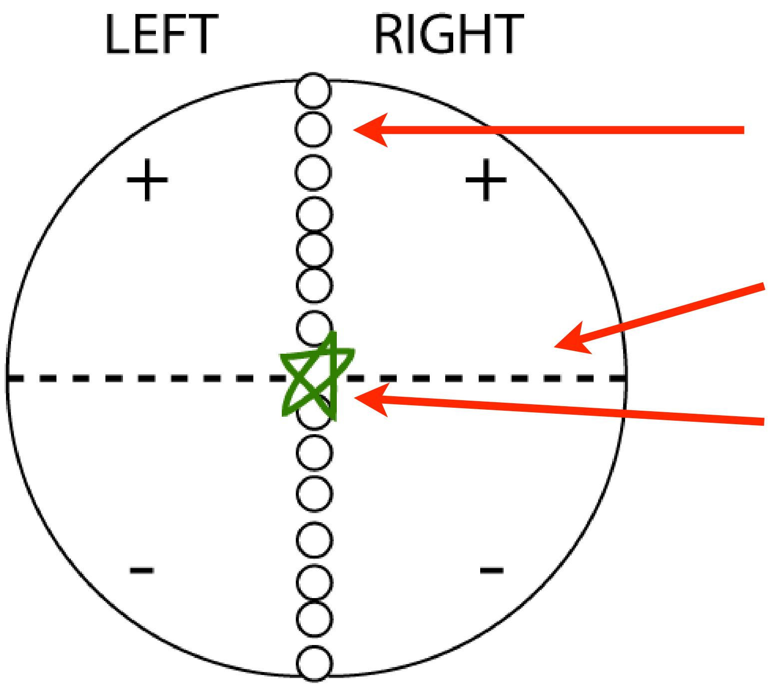


- visual field is cut in half, then upper and lower quadrants

Primary visual cortex (V1)

- distortions in V1: foveal representation is enlarged; periphery is low-resolution
- Simpsons in V1

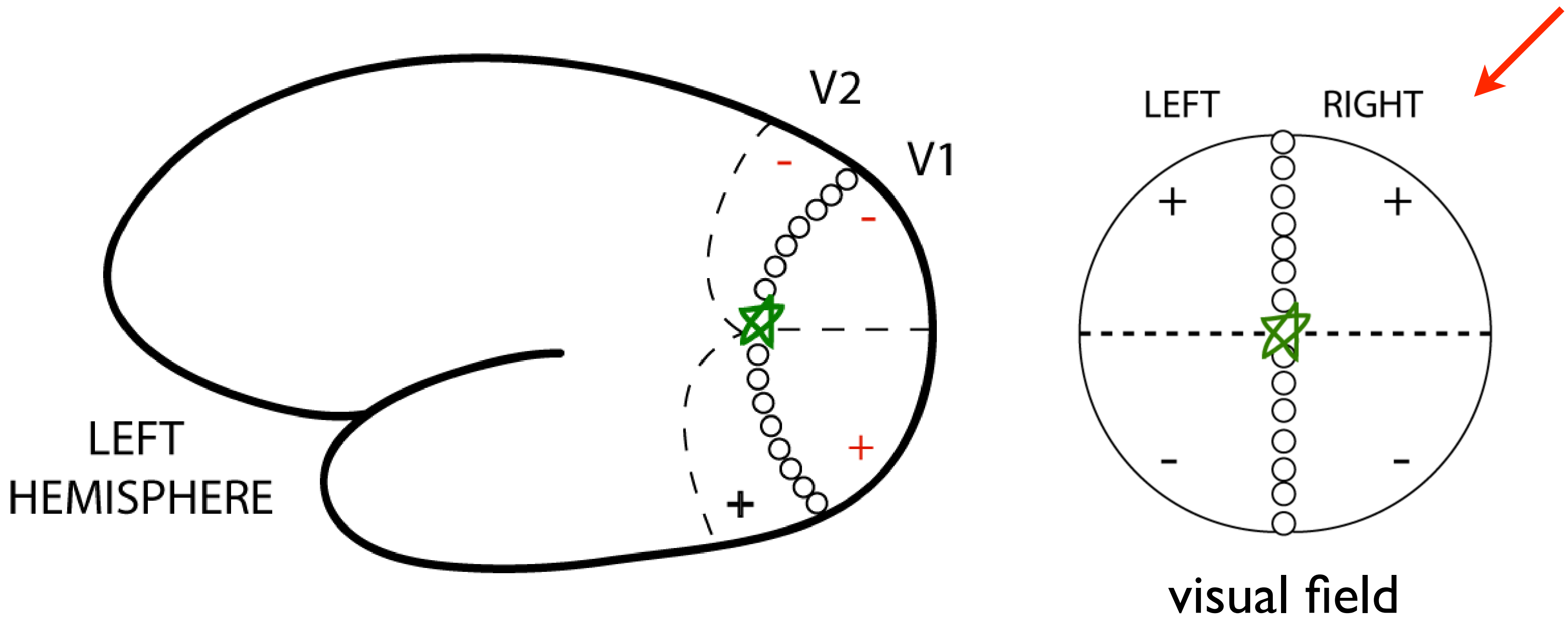
Representing the visual field



Visual field

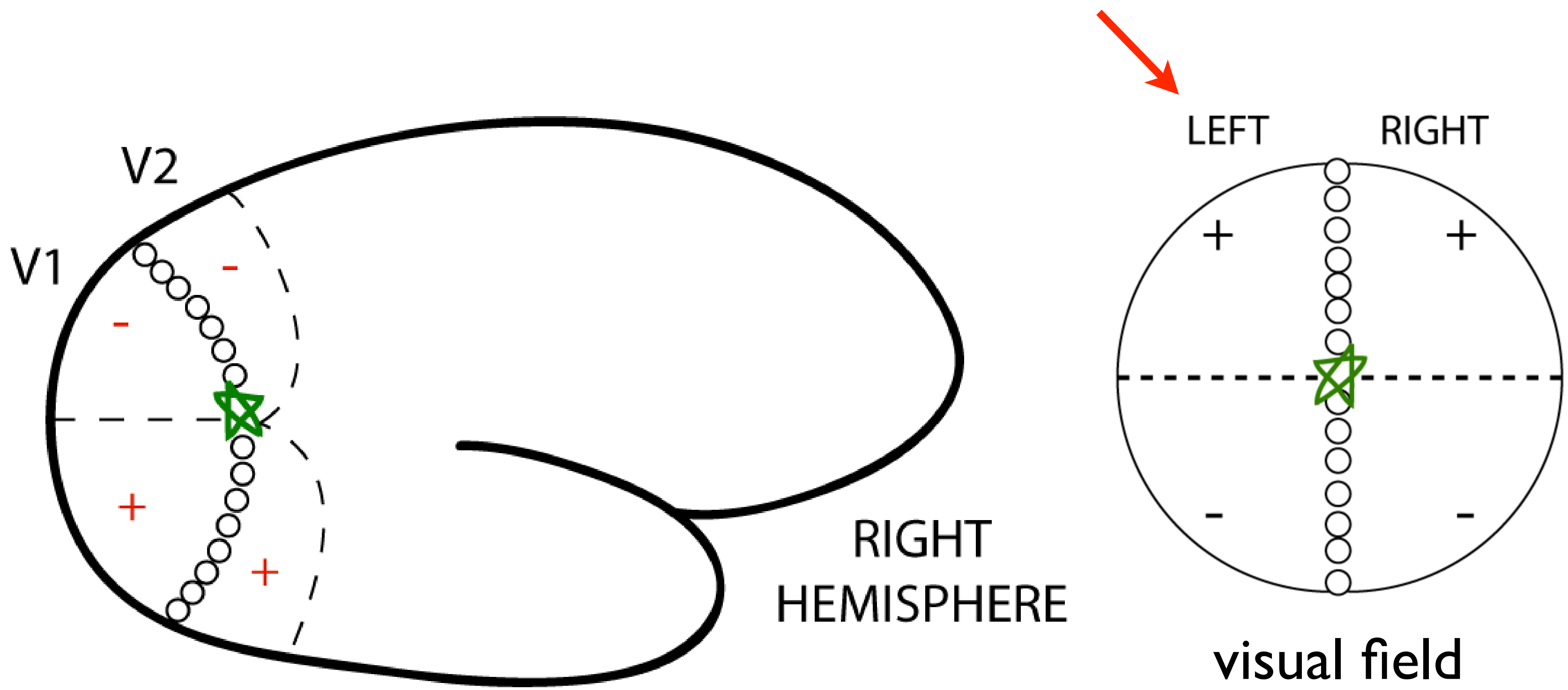
- vertical meridian
- horizontal meridian
- fovea
- upper, lower visual fields

Retinotopic maps in V1 and V2



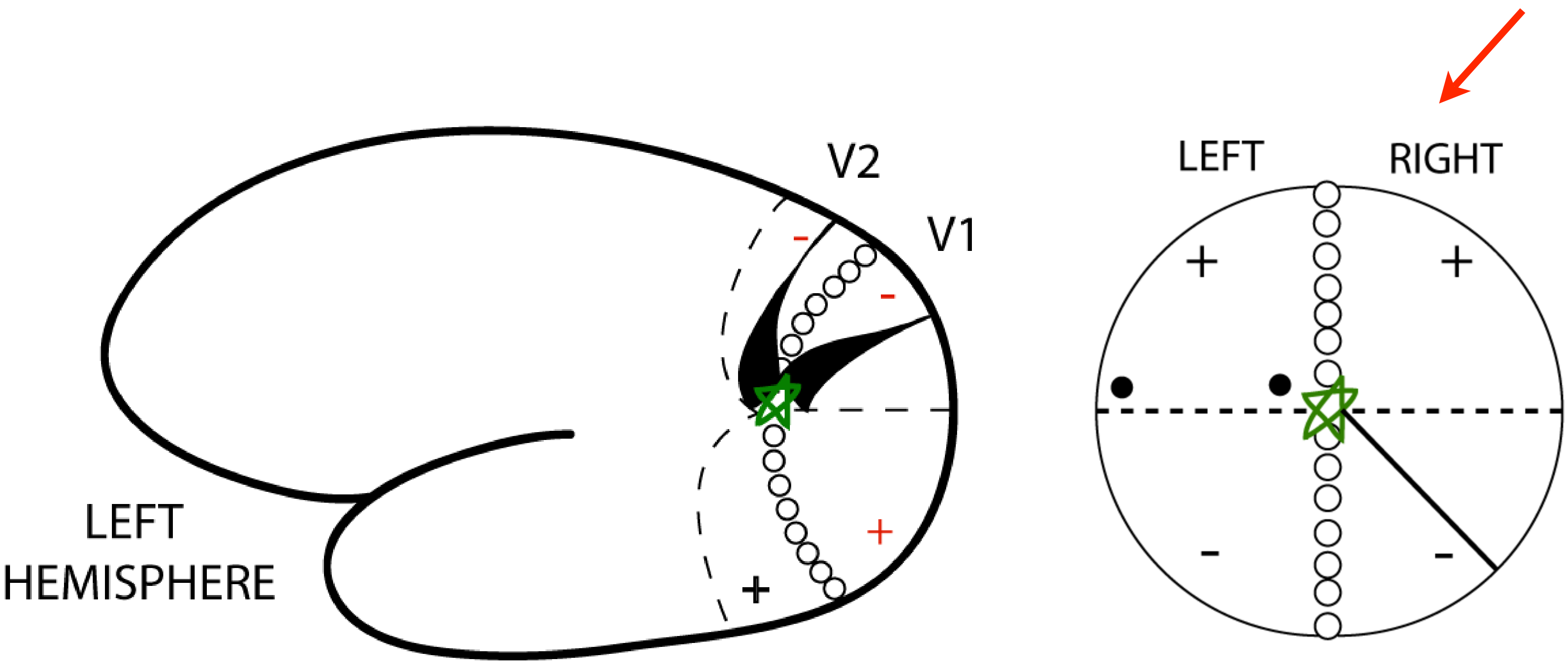
- Left hemisphere represents the RIGHT visual field
- upper and lower visual field representations are upside down
- V1 and V2 share a representation of the fovea

Retinotopic maps in V1 and V2



- Right hemisphere represents the LEFT visual field

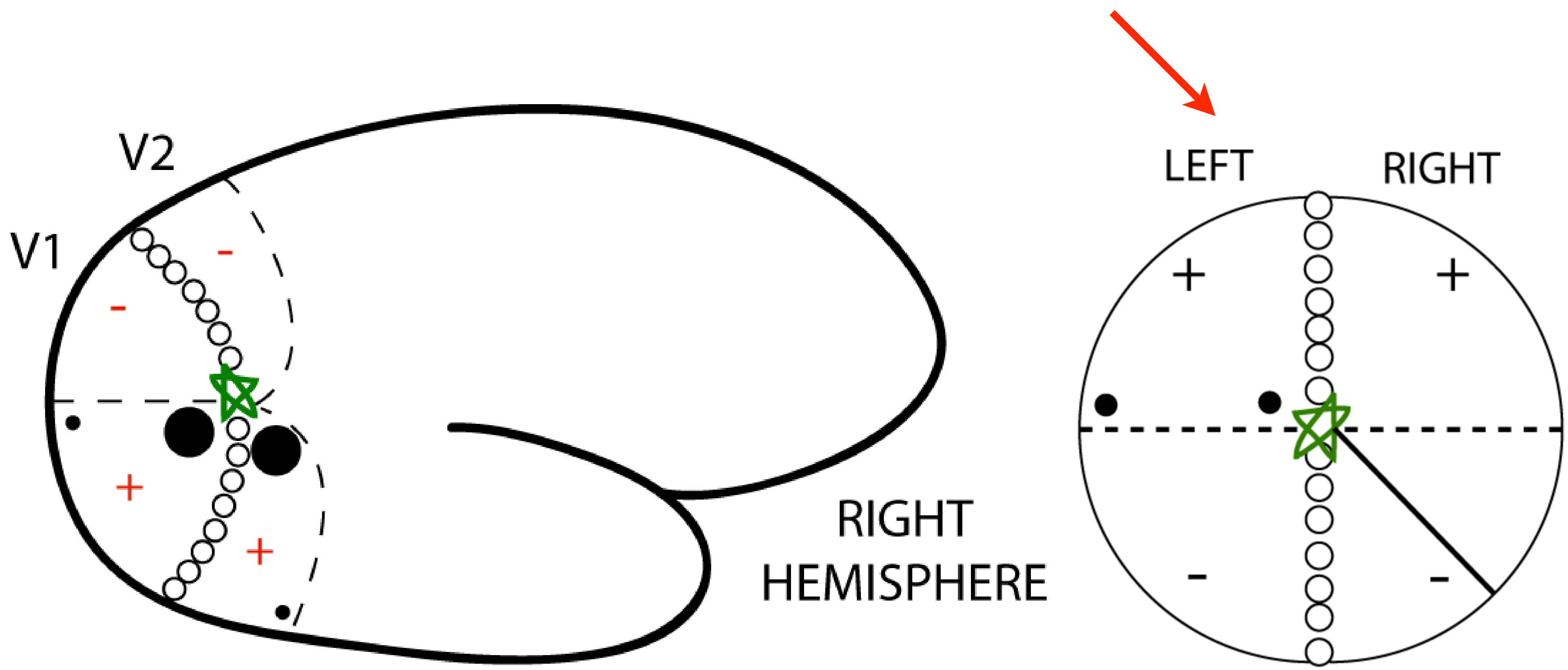
Retinotopic maps in V1 and V2



visual field

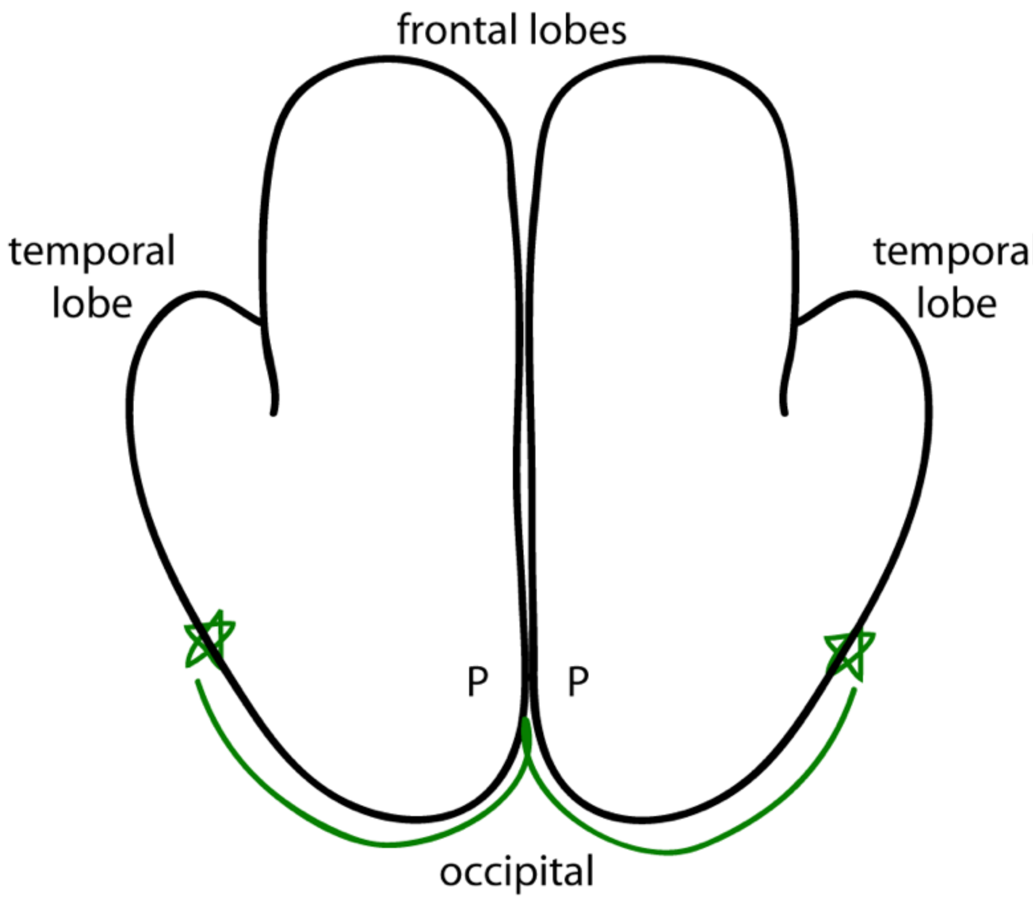
Only the line is represented - the only stimulus in the right visual field; note the foveal enlargement

Retinotopic maps in V1 and V2



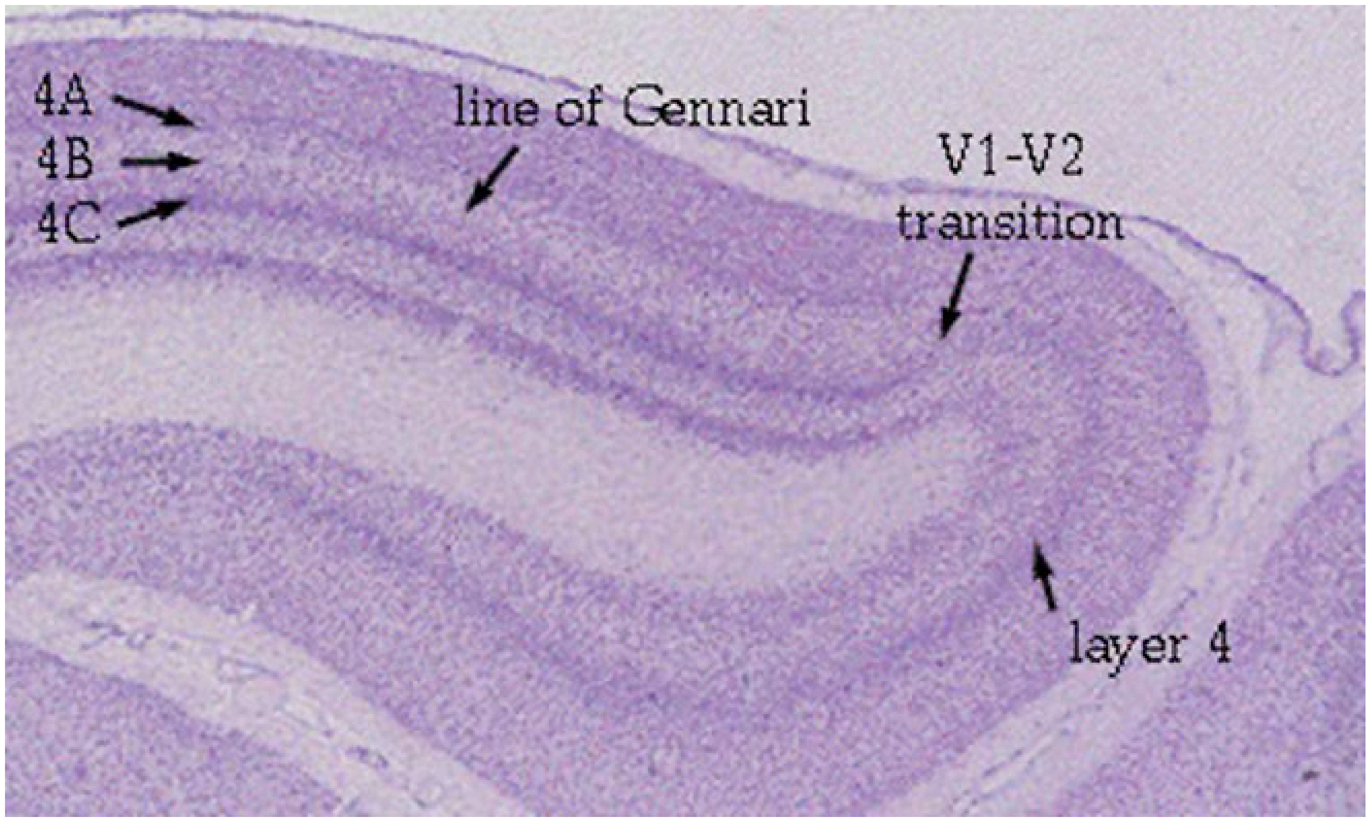
visual field

The 2 dots are all the right hemisphere sees - note the foveal enlargement of the dot closer to the fovea



- top view of left and right hemispheres

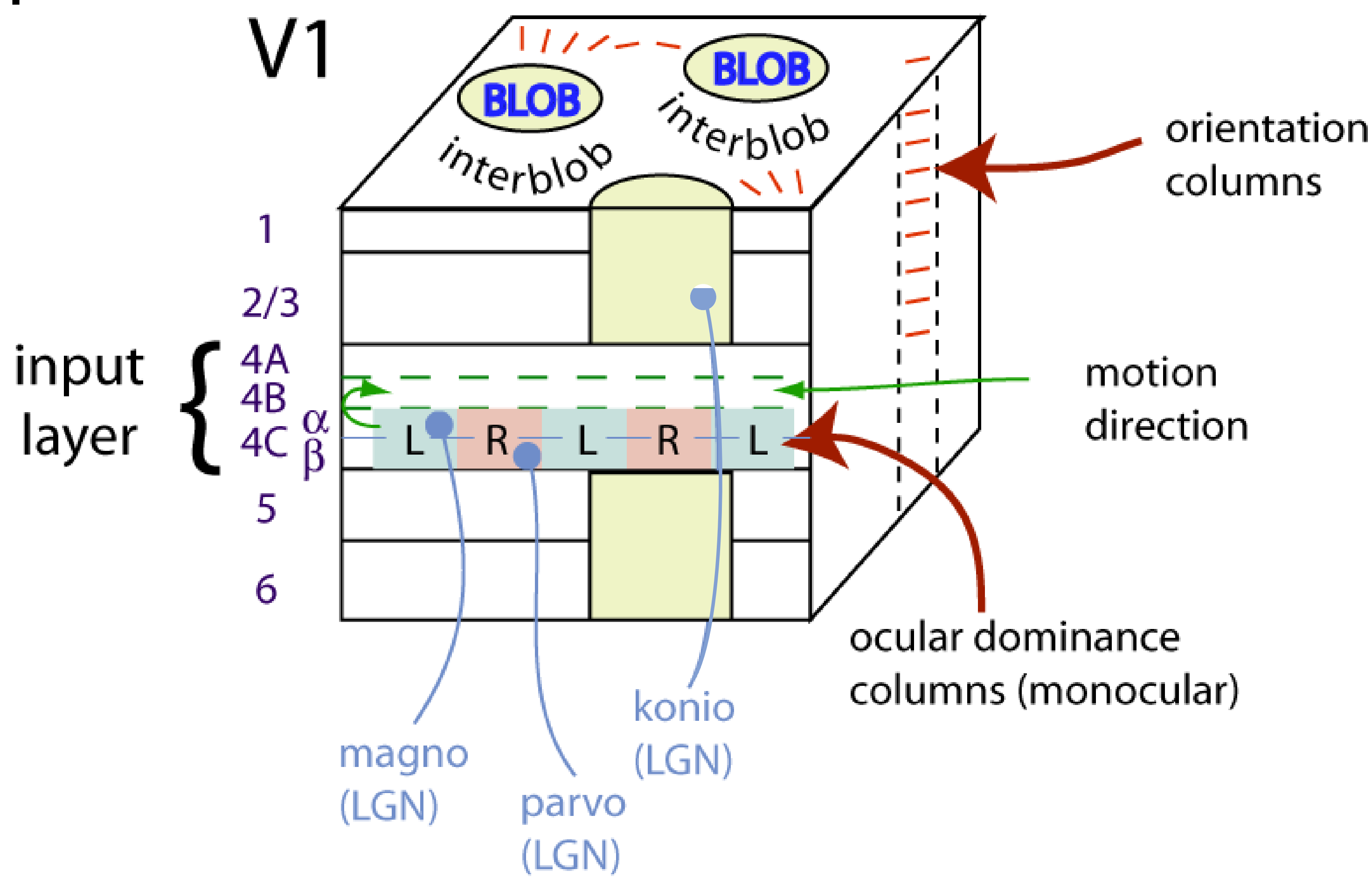
V1 = "striate cortex"



- "laminated"

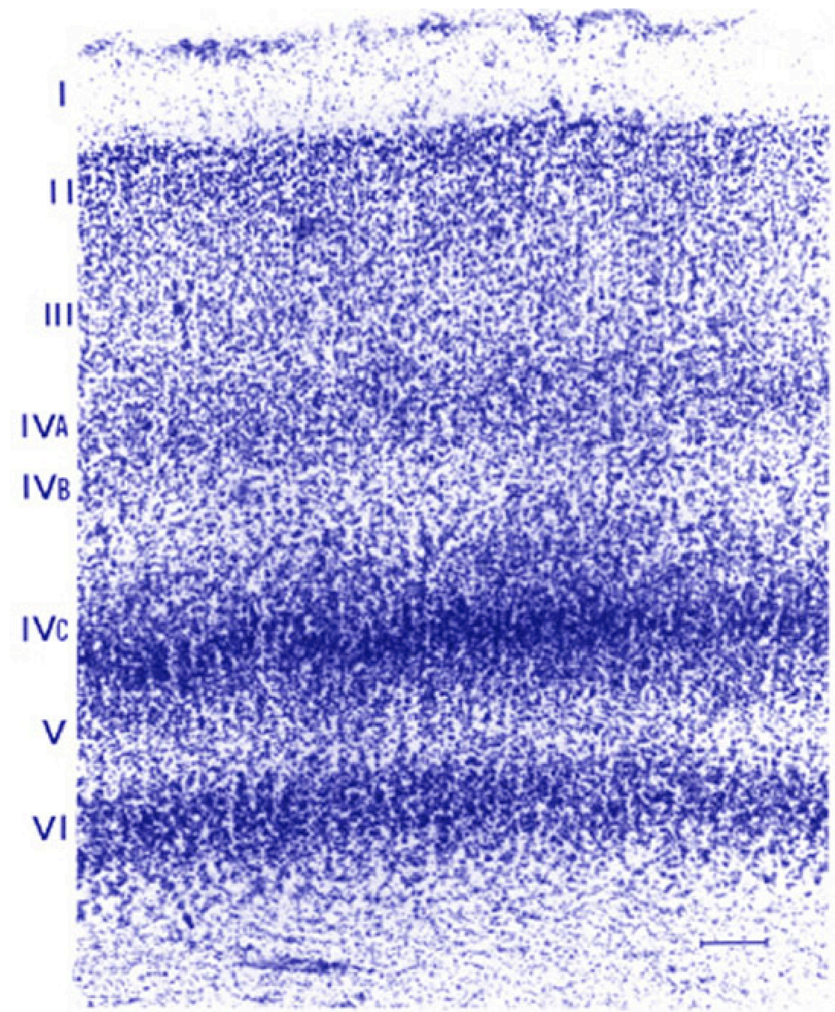
Organization of primary visual cortex (V1)

cross-section of V1



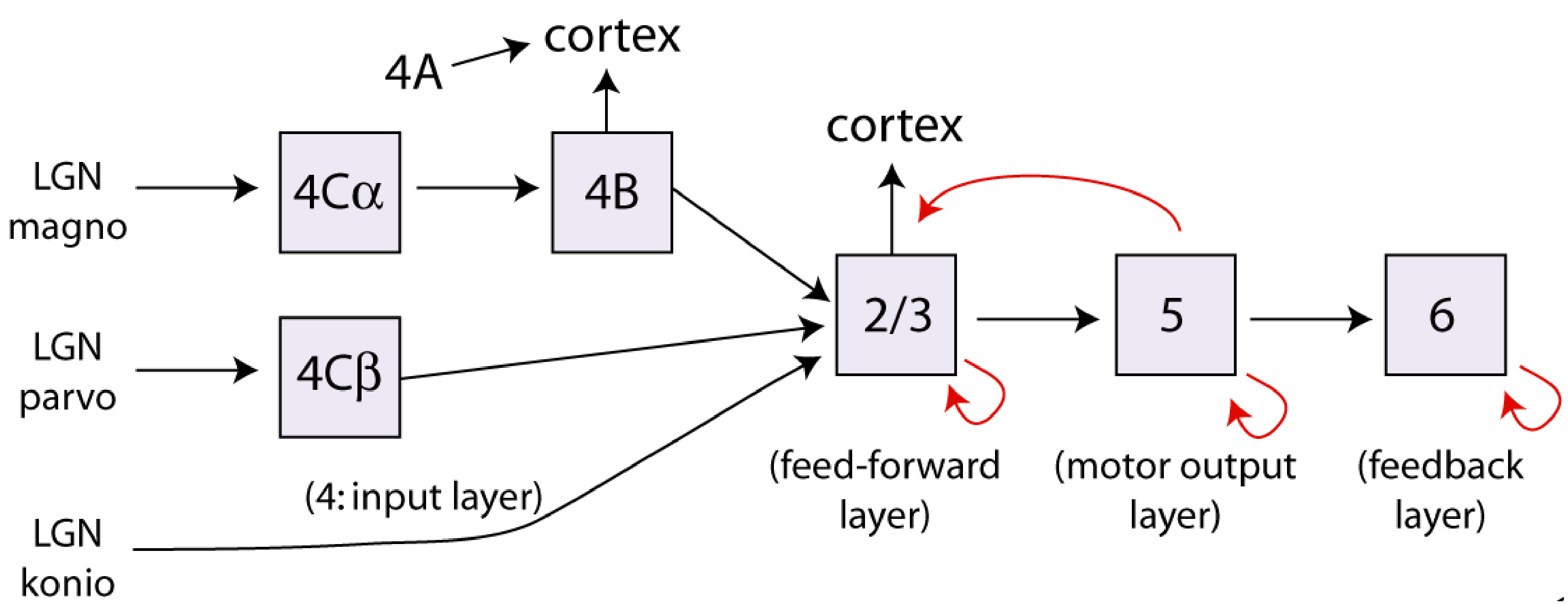
V1 cortical layers

- layer 4C in V1 gets most of the input from LGN
- layer 6 gets some
- layer 1: very few cells; primarily axons & dendrites



retina.umh.es/Webvision/ VisualCortex.html

Connections/Projections



- Inputs to V1 layers

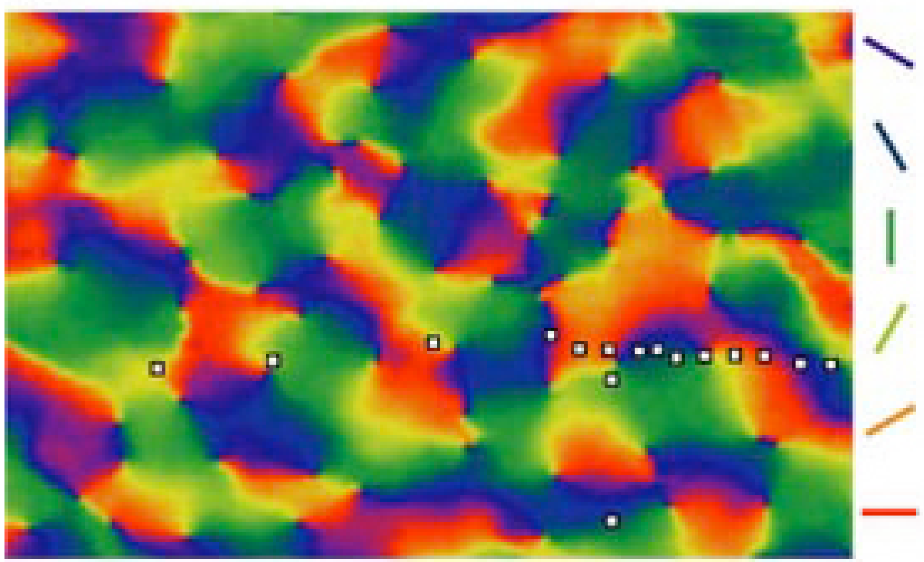
Parallel streams of information in V1

- interblobs (orientation-selective)
- blobs (brightness, color)
- layer 4b (direction of motion)
- layer 4C (ocular dominance columns)

1) Interblobs

- contain orientation-selective cells.
- Several kinds: simple, complex, hypercomplex

Orientation representation

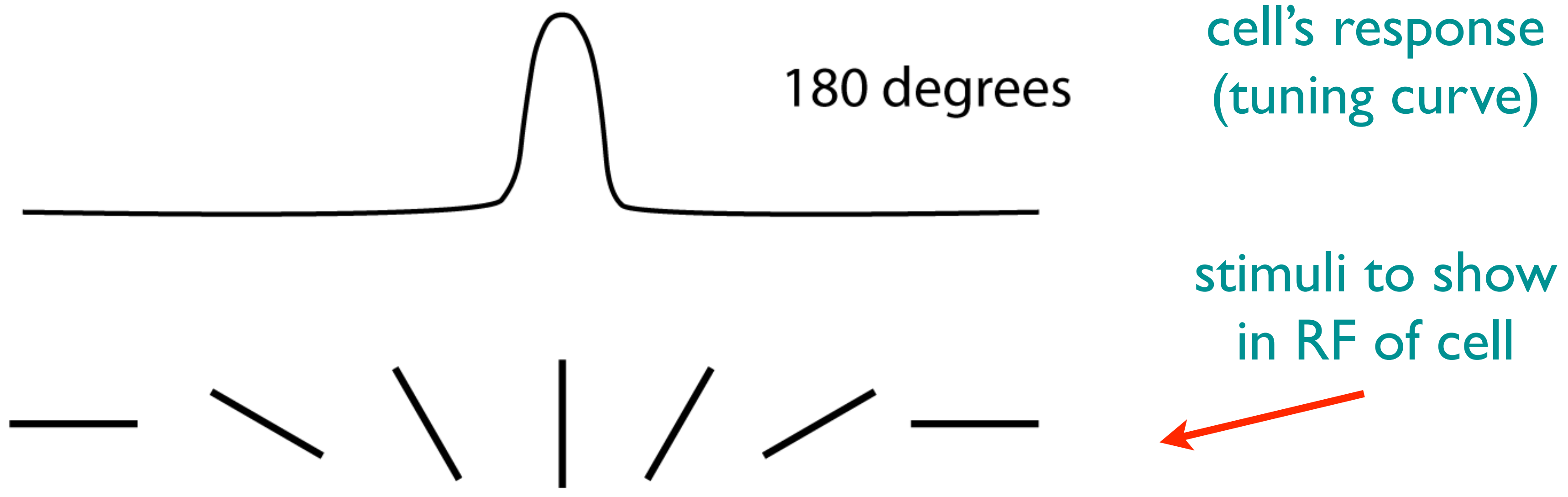


(top view of cortex)

- orientation selectivity varies smoothly across the cortical surface in V1

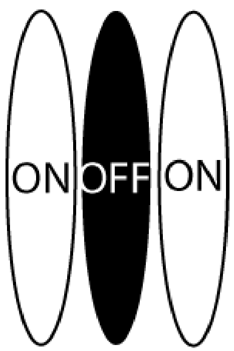
Squire et al., 2003

Orientation selectivity

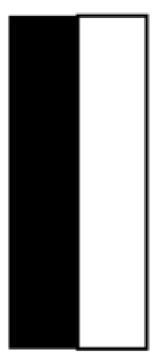


- How do we know if a cell is orientation selective and what orientation it prefers?

Simple cells

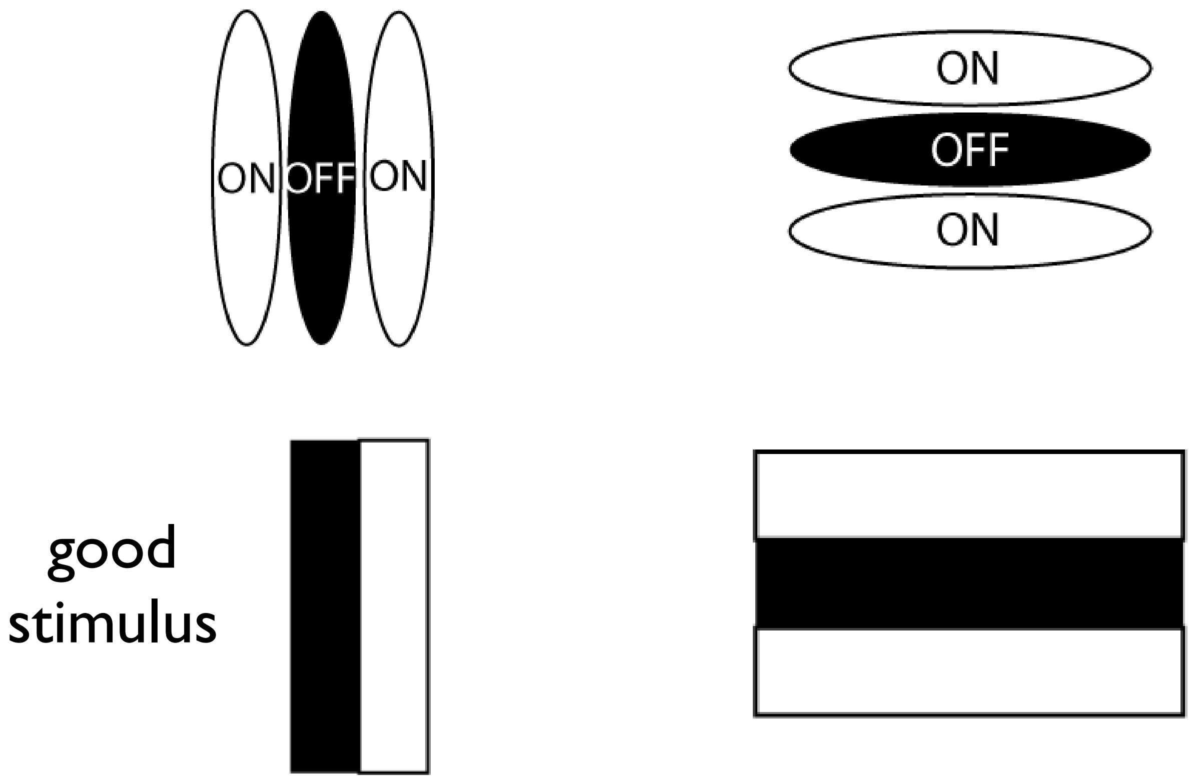


good
stimulus



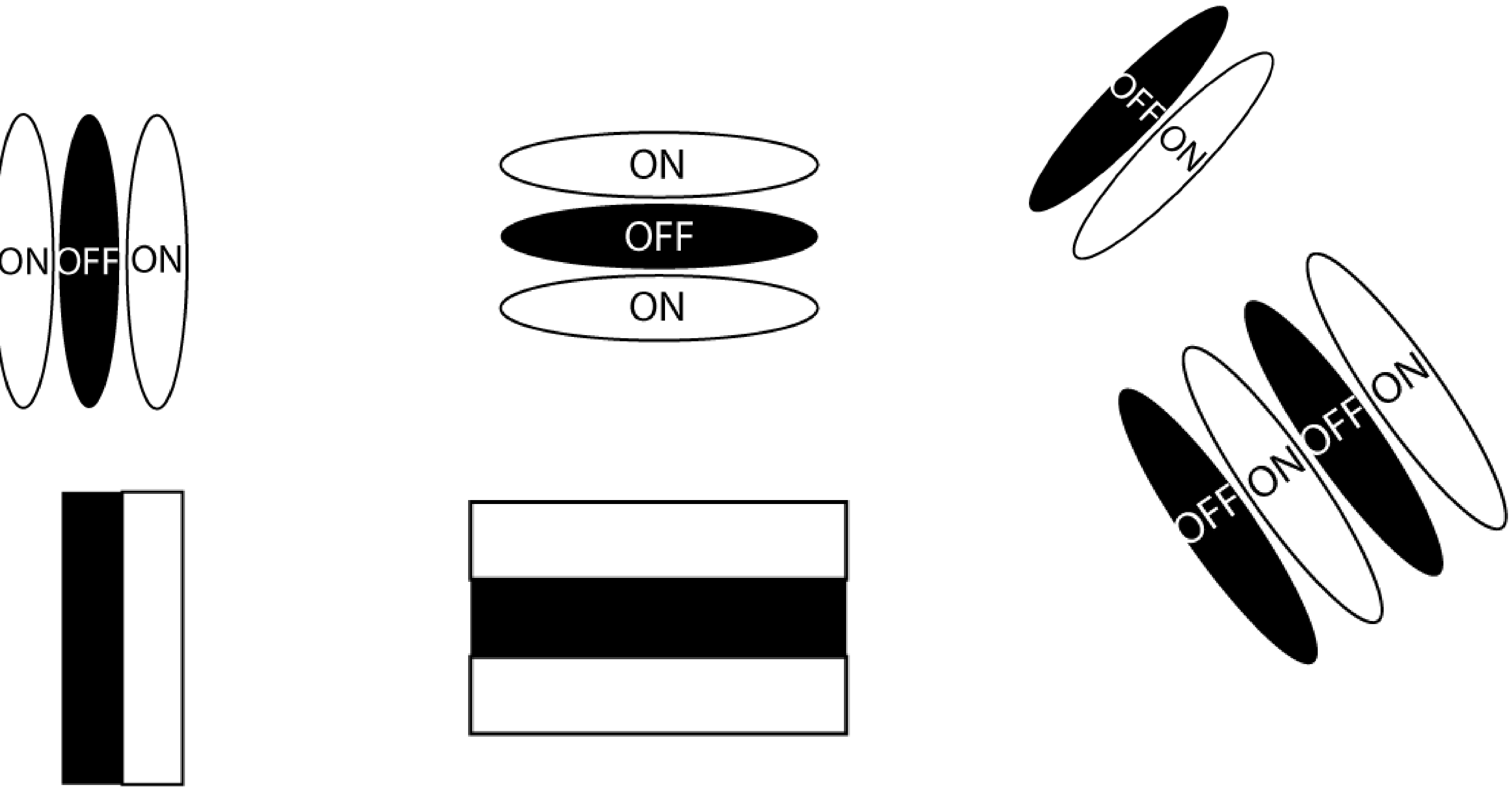
- simple cells have oriented elongated subfields that give ON or OFF responses

Simple cells



- simple cells have oriented elongated subfields that give ON or OFF responses

Simple cells

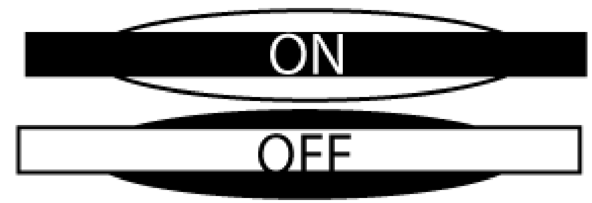


good stimulus

- simple cells have oriented elongated subfields that give ON or OFF responses - axis of subfields = orientation preference

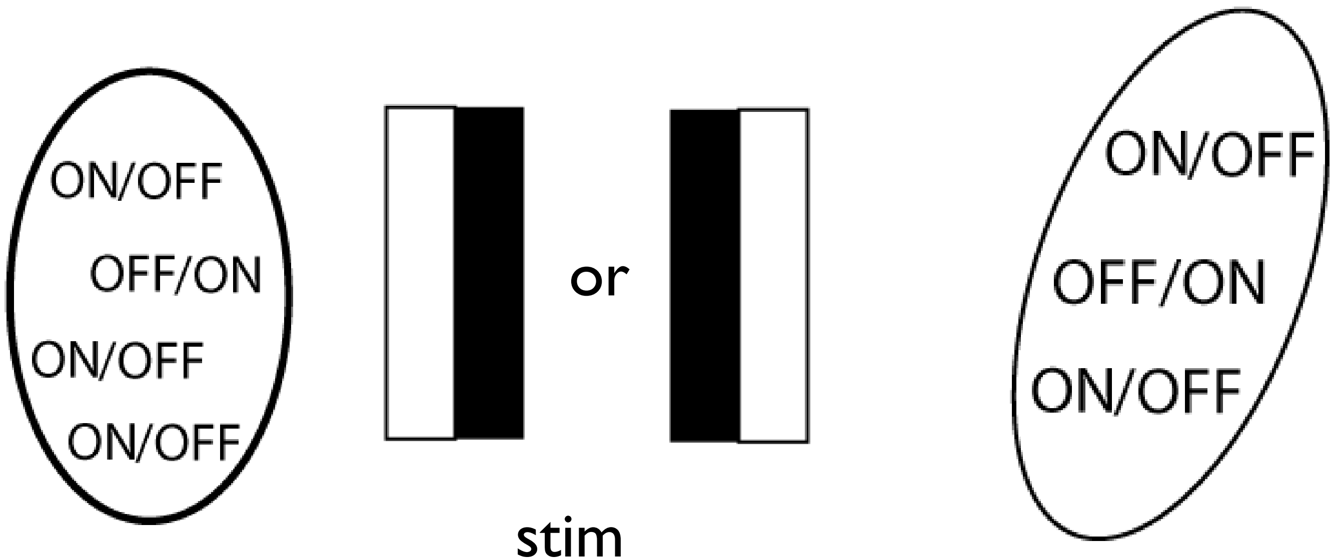
Simple cells

bad stimulus



- simple cells are good **edge detectors** that tell you precisely where the edge in the RF is
- But: confused by the sign of the contrast (ON-OFF vs. OFF-ON)

Complex cells

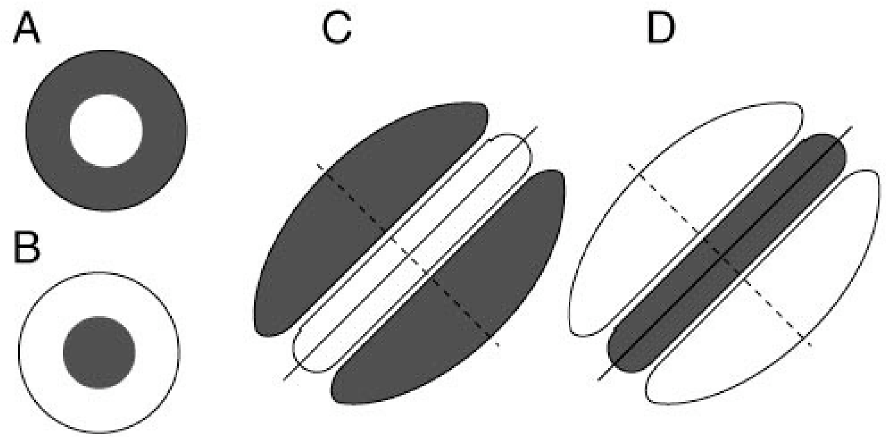


- complex cells do not have separate ON or OFF subfields, but respond ON/OFF at every point inside their RF
- also orientation-selective - axis of elongation of RF = orientation cell is selective for.

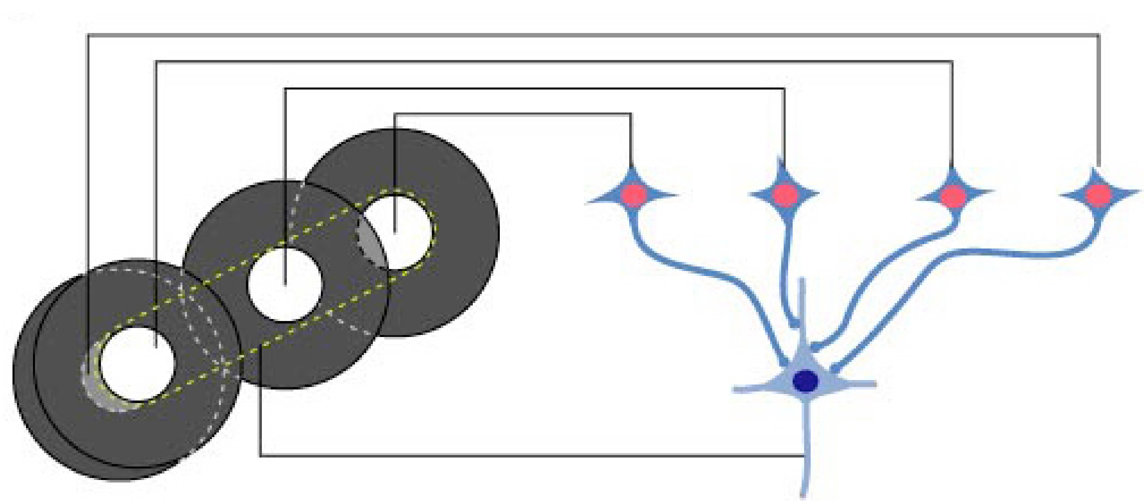
Complex cells

- Complex cells are more general edge detectors - don’t get confused by sign of edge, but can’t tell you where exactly the edge was in the RF
- as long as stim is correct orientation, can move it anywhere inside RF of complex cell -- will get good response

How to build a simple cell

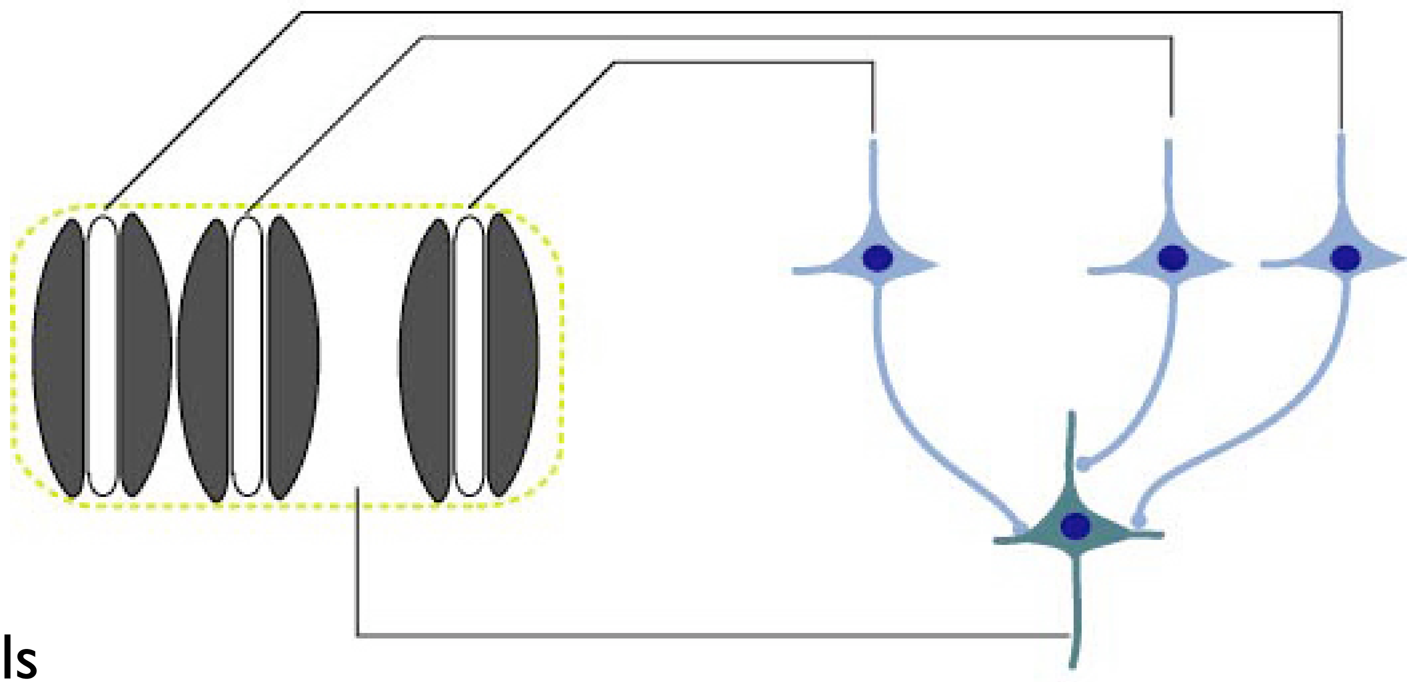


multiple LGN center-surround cells arranged in a line



Squire et al., 2003

How to build a complex cell



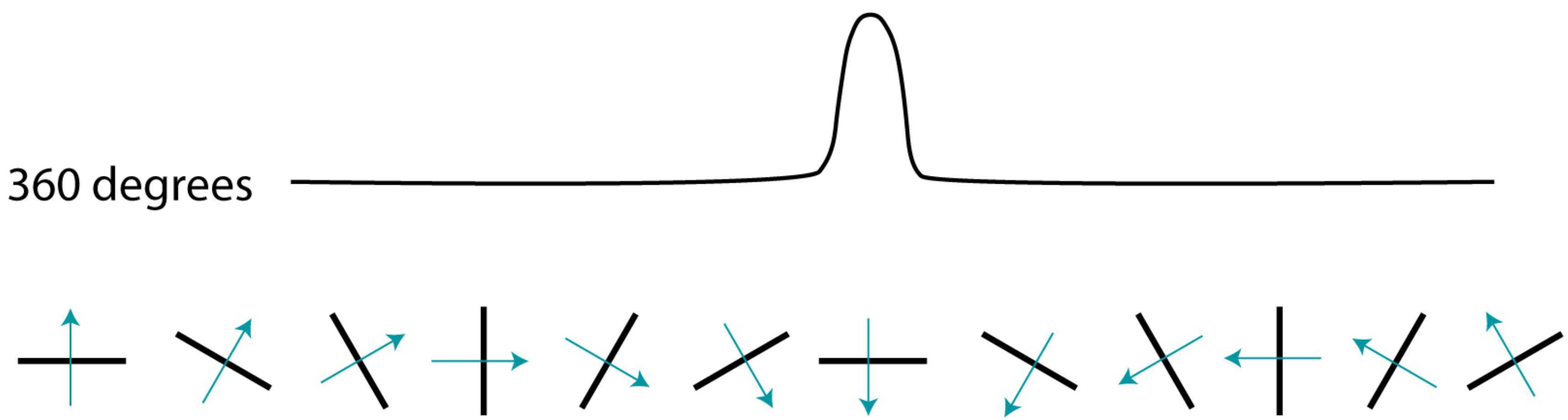
multiple
simple cells
with
matching
orientation

Squire et al., 2003

II. Blobs

- blobs: color and brightness detection
- animals that don’t see color still have them (→ brightness)
- not sensitive to orientation

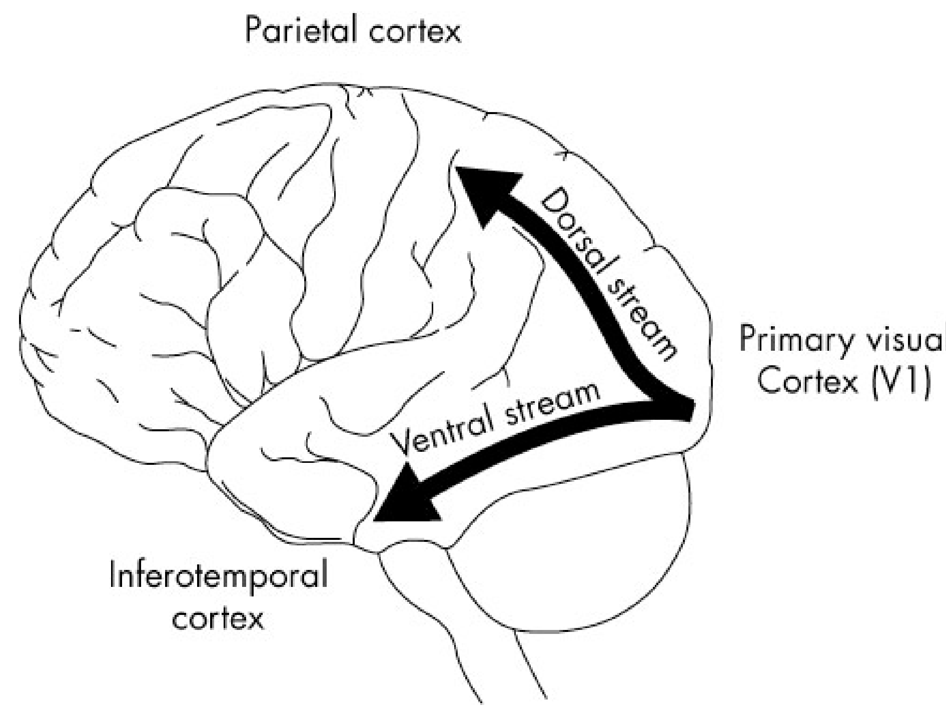
III. Motion direction selectivity (layer 4b)



- How to test for motion direction selectivity: vary angle of line presented to RF, move line across RF

Ventral and dorsal visual pathways

- ventral: object recognition ("what"):
- V1 → V2 → V3 → V4 → IT
- dorsal: "where or how":
- V1 → V2 → V3 → MT → MST (with V1 → MT also)



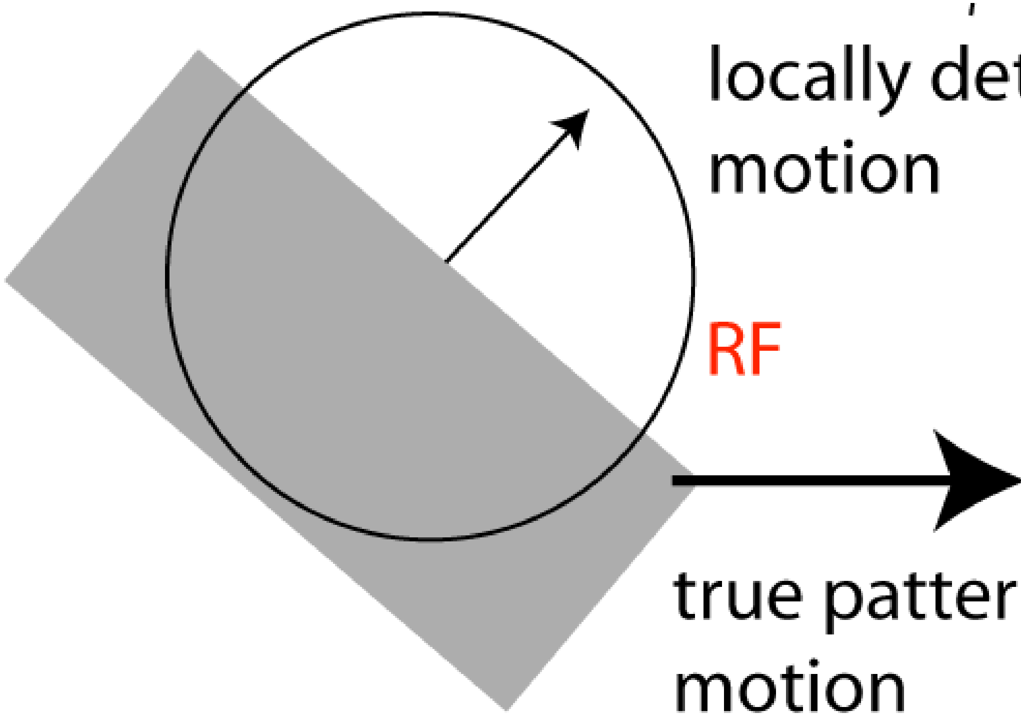
Aperture Problem

- several visual areas process visual motion: V1, MT, MSTd
- MT = middle temporal;
- MSTd - middle superior temporal dorsal area

The Aperture Problem

- I. For **Pattern Translation**
- http://journalofvision.org/4/10/9/fig1.swf

V1 receptive fields only detect motion perpendicular to edge



Flavia Filimon, Systems Neuroscience 2008

Aperture Problem and receptive field size

- V1 (layer 4B) neurons only detect the **local** motion - i.e. motion perpendicular to the **edge** visible in the cell's RF
- aperture problem is due to the **small receptive field sizes** of V1 neurons
- cells in higher visual areas have progressively **larger** receptive fields and therefore integrate more information across space

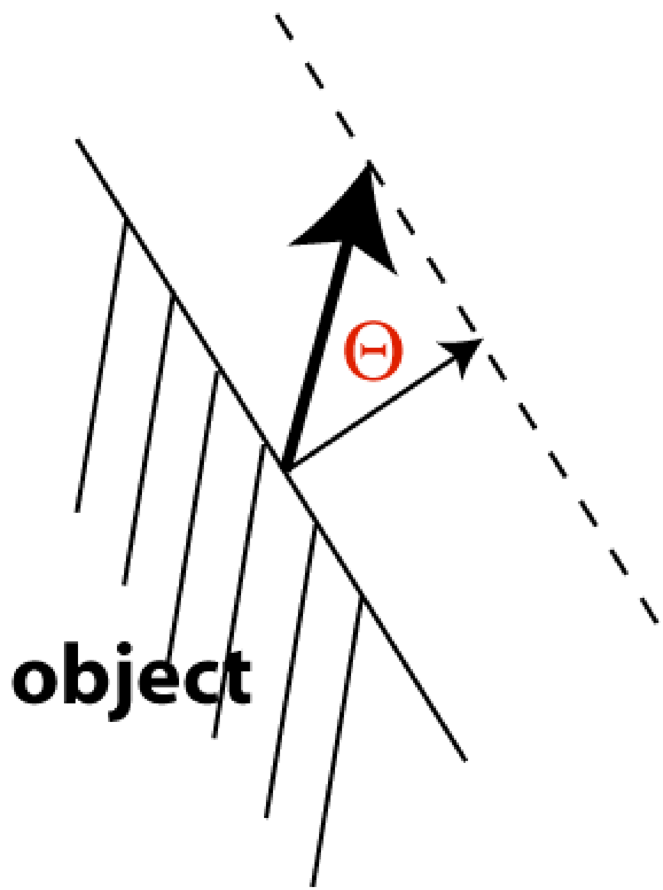
Aperture Problem and receptive field size

- V1 sees the world through “little straws”
  - V1 R.F. size: $< 1°$
  - MT R.F. size: 5-10°
  - MSTd R.F. size: $> 40°$

Conventions we'll use

- thick arrow = "**pattern**" (= object) motion
- thin arrow = "**local**" motion (locally detected)
- length of arrow = motion speed
- angle of arrow = motion direction

How to calculate local motion



- local = pattern $*$ cos θ
- or, simply draw line parallel to **edge/ contour** & tangential to pattern motion:
- local is perpendicular to edge, and bounded by the parallel line.

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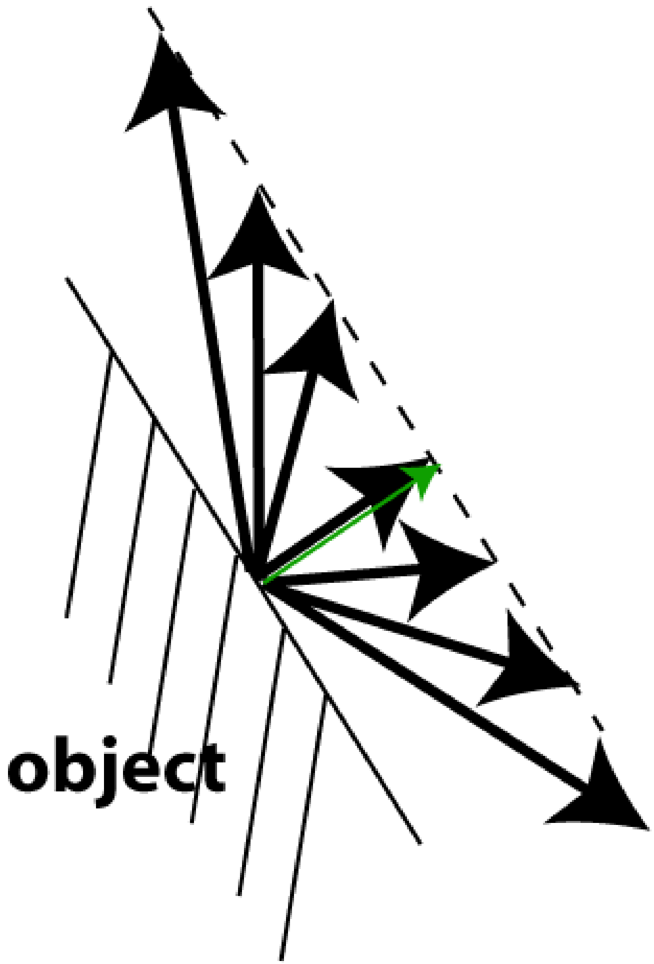
For each **local motion** there are multiple possible pattern motions



- each "**local**" has a family of possible **pattern** motions (within 180°)

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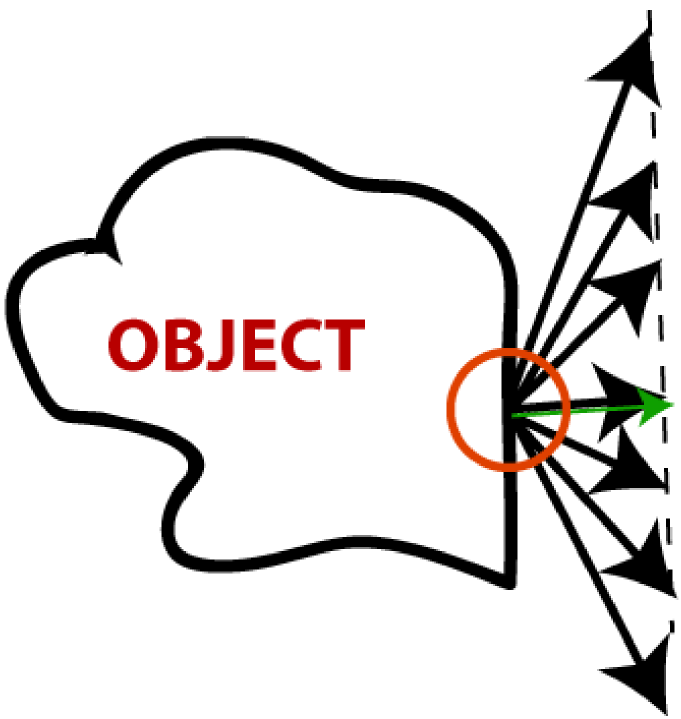
The view from V1



- each of the thick arrows could be the true **pattern motion**, given the detected **local motion** (green)
- red circle = one V1 R.F.

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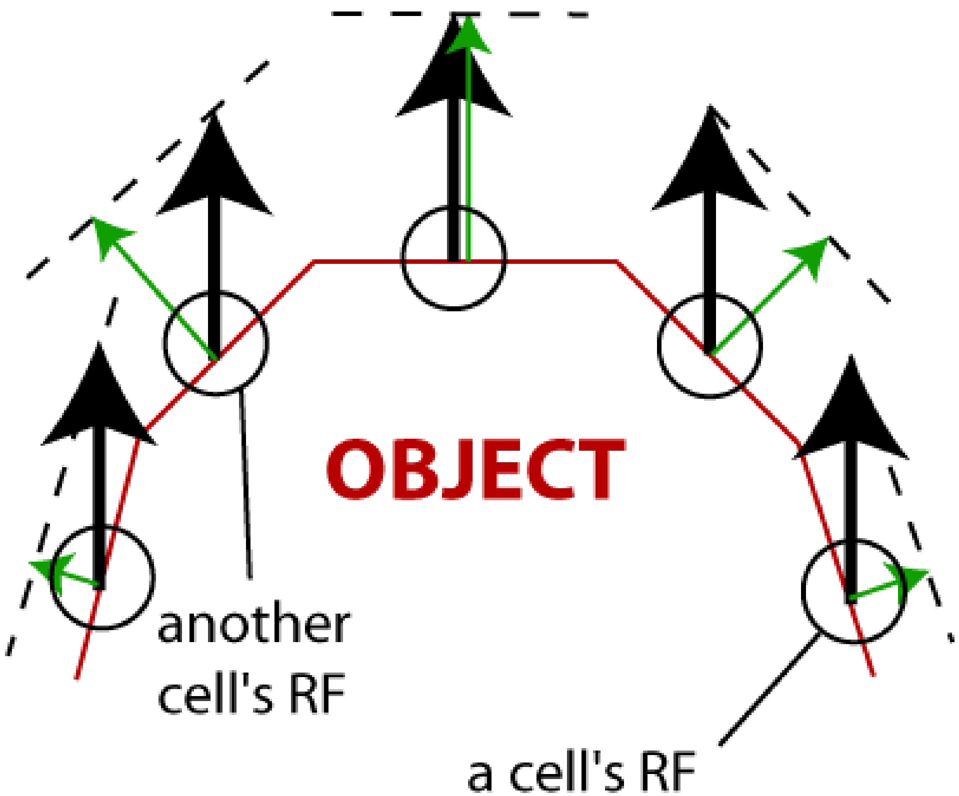
For each **pattern motion**, there are many possible local motions



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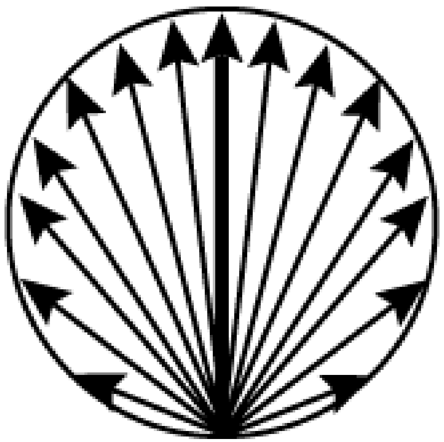
- each cell’s receptive field detects a different **local motion**, depending on edge orientation. (within 180°)
- re-draw pattern motion at each point to calculate local motion

Family of possible local motions given one pattern motion



- putting all reported local motions together
- (true pattern motion overlaps with local motion at center)

Remember arrows represent both motion direction AND speed!

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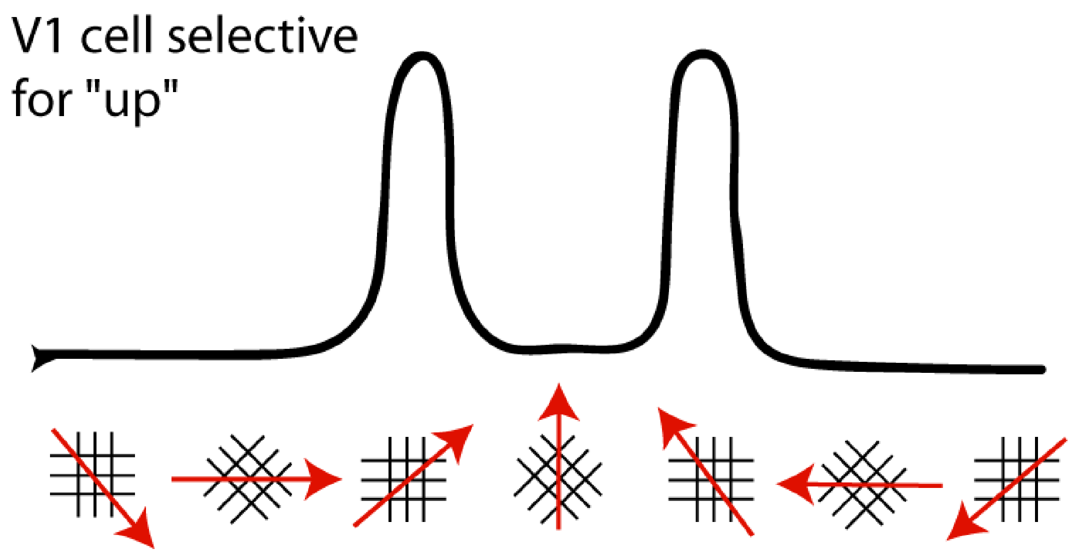
Evidence for aperture problem in V1



- tuning curve of V1 neurons for plaid pattern motion: V1 neuron is confused by local edges in pattern (object)
- V1 does not detect true **pattern motion**

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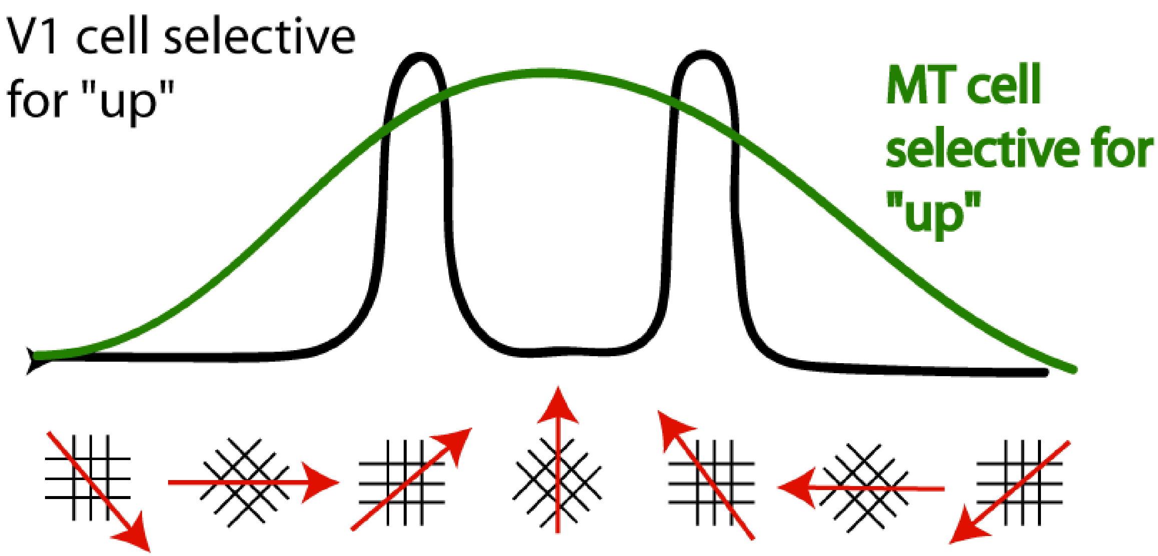
MT solves the aperture problem for translation



- bigger RF sizes in MT
- broader tuning curves in MT: MT identifies correct motion

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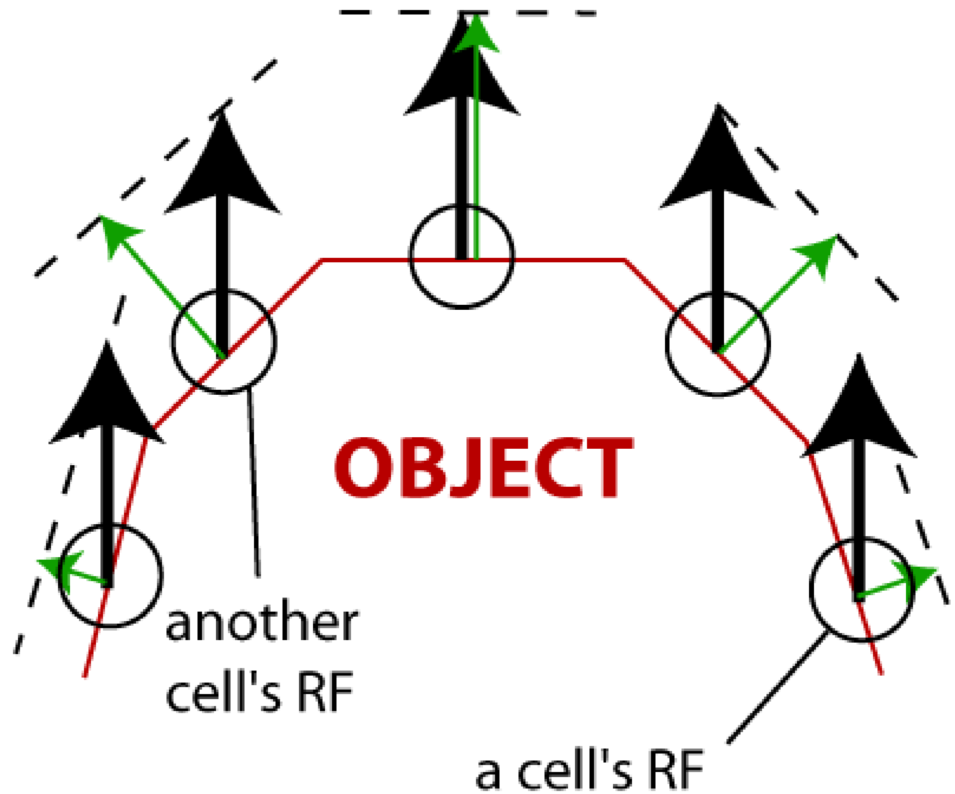
How does MT solve the problem?

- MT gets input from several V1 cells
- weighted average of V1 inputs reporting different local motions



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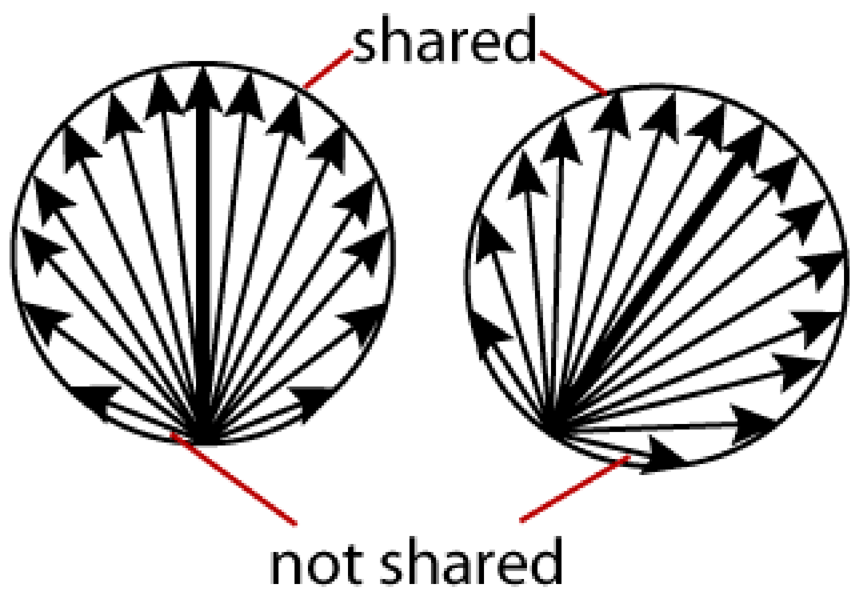
MT counts “votes” from V1



- the family of local motions consistent with one pattern motion that gets the most votes wins (greatest number of V1 inputs)

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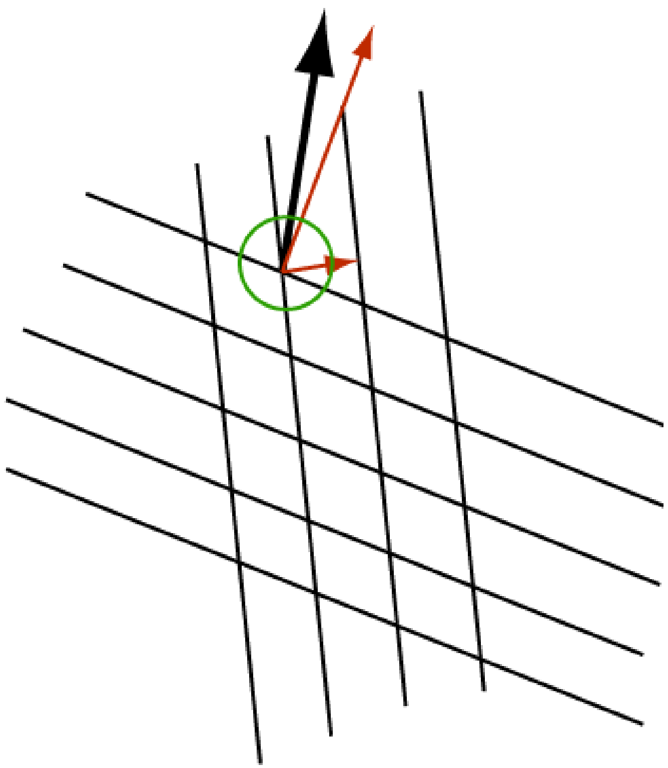
Why weighted average is necessary



- wrong answer if simply averaged local vectors

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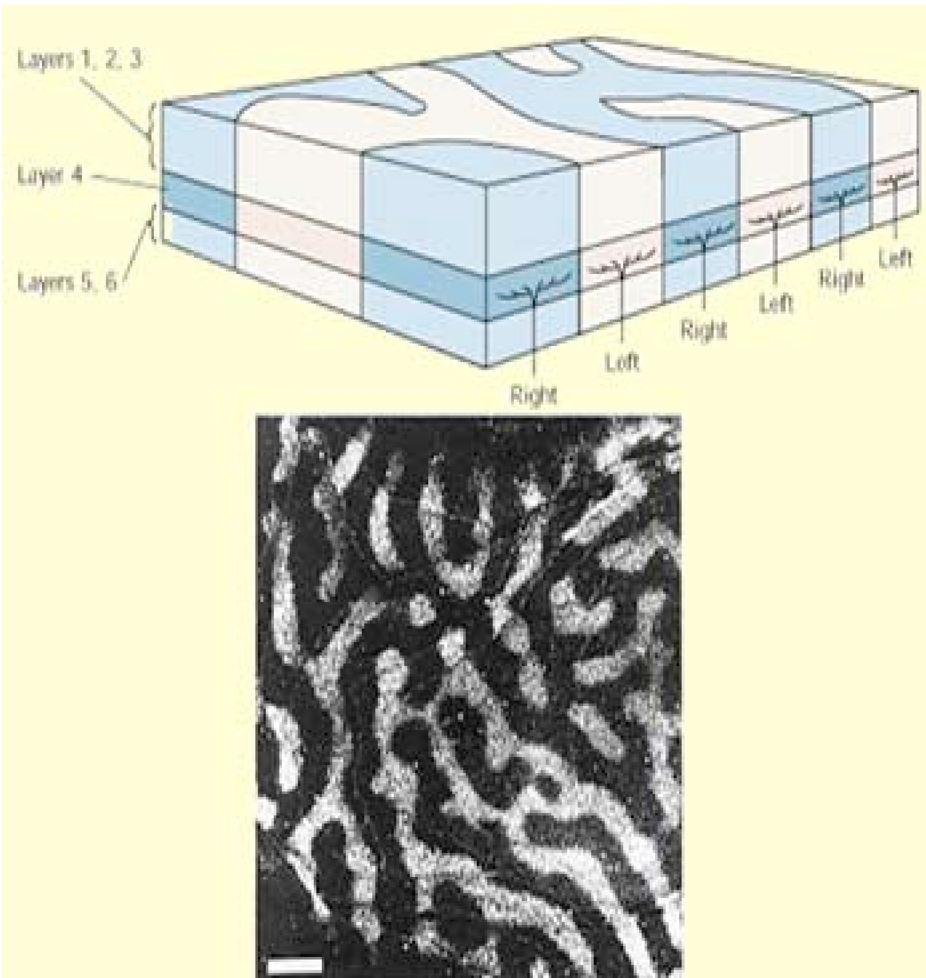
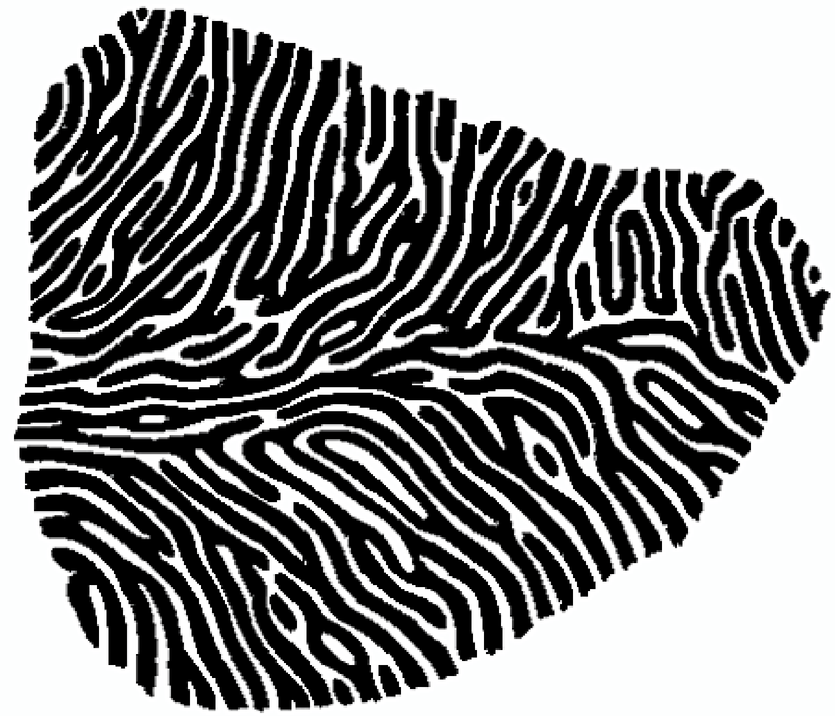
General principle

When integrating across space to solve some problem (e.g., aperture, orientation detection) detailed location information is lost

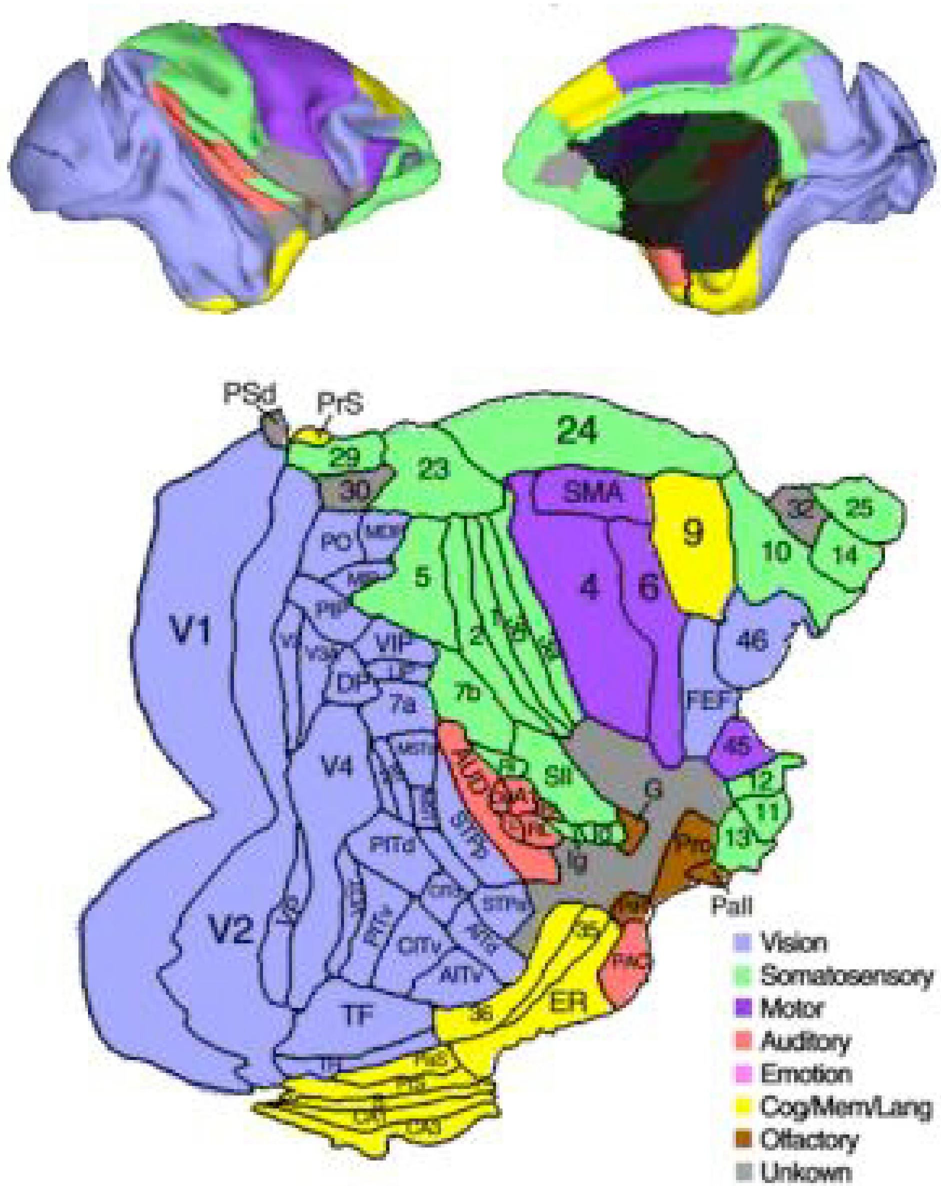
IV. Ocular dominance columns (4C)





top view of the cortex

Beyond V1 and V2



Cortical areas are defined using anatomical and functional criteria

Van Essen, 1995